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Some Engineering Characteristics of Small Portable Electric Lights for Caving

William W. Varnedoe, Jr.*

ABSTRACT

Various known parameters that affect the caving light are analyzed. The interaction of volume, weight, and cost is discussed with respect to length and brilliance of illumination. Lamps are discussed, and the factors of design life, operating voltage, wattage, and current are analyzed with respect to brilliance, expected operating life, battery drain, etc. Carbon-zinc, manganese, mercury, nickel-cadmium, silver-zinc, silver-cadimum, lead-acid, and Edison batteries are compared with respect to their peculiarities, energy per volume, energy per weight, and energy per unit cost. The interaction of battery and lamp is also discussed.

INTRODUCTION

Selection of a portable electric light for cave exploration involves an enormous number of interrelated parameters that make tradeoff studies very complex. As a first simplification, this paper will limit itself to battery-powered incandescent lamps, of a size to be mounted on a hardhat. Although there are inter-influences rather than interfaces between the lamps and their power sources, the two will be discussed separately. Because one cannot mentally juggle all of the parameters that actually interact, we will separate the lamp discussion from the battery discussion before talking about them together.

The brilliance of a light is measured in candlepower. A candle is defined as the amount of light emitted by 5 mm² of platinum at its temperature of solidification. In more familiar terms, the average carbide lamp emits about 2 candlepower. In an incandescent electric bulb, the power consumed multiplied by the luminous efficiency of the bulb is proportional to the temperature of the filament, which is, in turn, proportional to the brilliance. How long the bulb burns, assuming power is available, is a random variable that depends on the lamp design and is inversely proportional to its efficiency.

Each battery, when fully charged, contains just so much energy per unit volume. This power density is a characteristic of the battery type. Each type, however, can be constructed to allow some variation in rate of power withdrawal to achieve maximum power density.

The designed lamp consumption rate must match the designed battery withdrawal rate to achieve maximum overall efficiency. For the use of a lamp, design goals can be set. But, depending on which goal has highest priority (such as long life, brilliant light, compactness, cheap operation, etc.) there usually results an entirely different

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optimum design or choice of lamp and battery. These goals are personal choices. One caver may habitually make 20-hour trips; another may rarely be underground over 4 hours. One might need a brilliant light, while another would prefer to sacrifice brilliance for a more compact rig. Cavers in Idaho will find their cave temperature may make a Texas caver's favorite rig almost worthless, and so on. The possible combinations and compromises are almost endless, and none can be claimed "best" except for a restricted location, use, and caving preference.

Generally, electric headlamps share common advantages of being convenient to use and reliable. The very wide choices available are, in a way, also an advantage. The versatility of choice enables a caver to optimize his caving light to fit his particular needs or whims. There nearly always exists a combination for a given need.

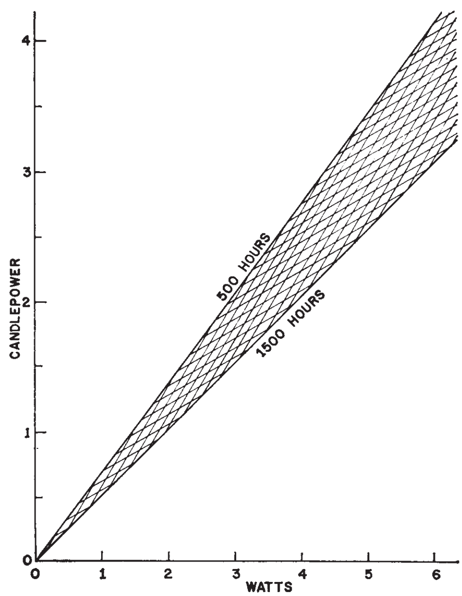

Figure 1. Brilliance (in candlepower) as a function of power consumed (in watts) for miniature incandescent lamps.

Lamps

The catalog listings of miniature lamps give design voltage, design current, bulb shape and size, base type, and often design life. The power in watts consumed by a lamp is the product of the potential in volts and the current in amperes.

Figure 1 shows the brilliance that can be expected from bulbs operating at power levels usually found in caving lights. As a point of practical departure, the average well adjusted carbide headlamp gives about 2 mean circular candlepower.* This is roughly equivalent to a 3- to 4-watt bulb, for example, a No. 31 or 405 bulb operating as rated. Note that a single line is not drawn in Fig. 1, because some bulbs are designed to operate at higher filament temperatures and, hence, at higher luminous efficiency. They are more delicate and their design life is shorter than more rugged but less efficient designs.

Lamps, however, are seldom operated exactly at their design values. To calculate the actual performance of a bulb operating at voltages even slightly off of design values we must refer to Fig. 2, which shows how operating values of candlepower, current, and life expectancy vary with operating voltage. These curves are presented as a ratio of actual to design values. Thus, as operating voltage varies from the design voltage, one can calculate how the actual candlepower, current, or life will differ from their design values.

Figure 2 shows that a mere 22% increase in operating voltage over design voltage will double the brilliance but reduce the life to only 6% of its design value. The hotter a filament is operated, the more fragile it becomes. Thus, the life figure, although expressed in time, is also a measure of ruggedness. A design life of 10 hours does not mean that all bulbs will necessarily burn out after 10 hours of use. Design life is an average burnout time taken from laboratory tests, and it covers a rather wide dispersion. The design life value can best be used as a relative measure of ruggedness

* This is based on tests run Dec. 8, 1971 using a Pritchard Photometer to measure the light output from a Justrite lamp with a fresh load, flame adjusted to 1¾ inches long.

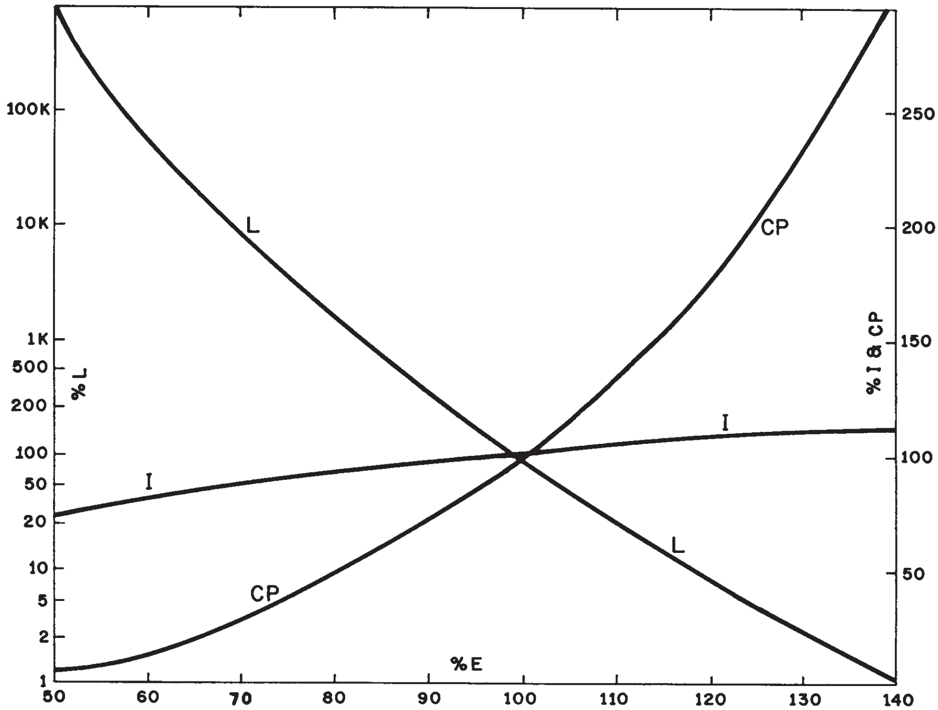

Figure 2. Miniature lamp operating parameters as functions of actual operating voltage. Each axis represents a percent ratio of actual to design values.

in comparing bulbs. In practice, caving lamps can be operated at a life value of 1 hour, but of course, many spare bulbs would have to be carried if the lamp were operated at such low values; and this is not considered good practice.

Lamps come in a variety of glass envelope shapes: spherical, teardrop, cylindrical, etc. In few cases does this matter, although the spherical shape is theoretically best. The filament in such small lamps is, itself, small enough so that it does not appreciably spread beyond the focal point of the reflector.

The apparent brilliance of a light source can be greatly enhanced by use of a reflector and/or a focusing lens. For a sharp beam, the filament of the lamp should be located at the focus of a highly polished, parabolic reflector. A reflector (lamp assembly) diameter of 3 inches is probably an upper practical limit, and 1¾ inches seems a good minimum. The beam can be spread to a flood in several ways. A less-than-parabolic reflector can cause a flood-type light, a spot with side flood, or any combination in intensity of these. A grooved glass cover plate will also scatter a portion of the beam into side light. Auto headlamps use this technique. Moving the filament "out-of-focus" will also have a broadening effect but may create dark spots or rings in the light beam.

The candlepower discussed so far, and as listed in lamp data catalogs, is in reality mean circular candlepower, that is, the mean of all light emitted in all directions, without any reflector or lens. This is the only fair way to compare bulbs alone since their housings vary so much.

The current of incandescent lamps does not rise in linear proportion to voltage because the resistance of the filament rises as it becomes hotter. In technical language, an incandescent bulb is an irregular non-linear load. Figure 2 also shows how the ratio of operating current to design current varies with the ratio of operating voltage to design voltage.

Let us take an example. The PR-2 is a common flashlight bulb rated at 2.4 volts, 0.5 amperes, 15 hours. When operated with two common dry cells, the PR-2 has an operating voltage of 3 volts or 125% of design. The current will be 120% of design or 0.6 amperes. The brilliance will be 200% of design and the life $0.04 \times 15 = 0.6$ hrs. By experience, we know that flashlight bulbs are delicate and often burn out if we give the flashlight a hard blow.

Commercially available lamps are listed in Table I. Only lamps with miniature

TABLE I. Useful Commercial Miniature Bulbs. All listed bulbs have miniature screw bases except the PR types, which have a flanged base. Bulb Type letters: G = Globular, T = Tubular and B = Tear drop. The numbers are sizes in ⅛'s of an inch.

Bulb Number	Design Candlepower	Design Voltage	Design Current	Life, Hours	Bulb Type
249	1.1	2.1	0.9	3,000	G 5½
35	1.3	2.5	0.8	150	G 5½
248	1.3	2.5	0.8	150	G 5½
8-147	1.3	2.8	0.44	?	T 2½
PR-3	1.5	3.57	0.50	15	B 3½
8-486	1.65	3.6	0.5	50	G 3½
365	1.6	3.69	0.5	15	G 3½
13	1.0	3.70	0.3	15	G 3½
403	1.0	4.0	0.3	30	G 3½
8-484	3.5	4.0	0.8	?	G 6
PR-13	2.1	4.75	0.5	15	B 3½
PR-15	1.9	4.8	0.5	30	B 3½
PR-17	1.1	4.8	0.3	30	B 3½
27	1.4	4.9	0.3	30	G 4½
425	2.3	5.0	0.5	15	G 4½
502	0.6	5.1	0.15	100	
153	7.9	5.8	1.1	50	G 6
157	7.9	5.8	1.1	50	G 6
PR-12	3.1	5.95	0.5	15	B 3½
1482	2.2	6.0	0.45	100	G 4½
8-710	4.5	6.0	0.80	15	G 6
8-254	6.1	6.0	1.05	300	G 6
PR-24	2.0	6.15	0.3	15	B 3½
31	2.0	6.15	0.3	15	G 4½
605	3.4	6.15	0.5	15	G 4½
405	1.9	6.5	0.5	500	G 4½
63M	3.0	7.0	0.63	1,000	G 6
50	1.0	7.5	0.22	1,000	G 3½
419	4.9	8.0	0.6	50	G 4½
426	1.6	8.0	0.25	250	G 4½
870	9.00	8.00	0.90	50	T 4½
993	3.4	9.83	0.3	15	G 4½
965	6.00	9.84	0.5	15	T 4½

screw bases or miniature flange bases are listed; also, most lamps below 1 candlepower (CP) are omitted, as well as those with a life figure too low to be useful in caves.

Mine service headlamp bulbs usually draw more current than the flashlight series of bulbs. So, while they are much more rugged, they are of a higher wattage and brilliance. Such lamps are preceded by the letters BM. These BM bulbs are expensive and not generally available, but they may be purchased from mine service supply sources. A representative list is given in Table II.

Batteries

A cell is the basic electrochemical unit of a battery. All of the characteristics of batteries are determined by their cells. A cell consists of two metals called electrodes immersed in a conducting liquid called an electrolyte. The basic chemical properties of the metals and the liquid determine the cell voltage. Most practical cells use a metal oxide electrode and a metal electrode in an alkaline solution, although carbon is also used in lieu of a metal oxide in one type of cell and an acid is used as the electrolyte in another. The voltage or potential is independent of the physical size and shape of the cell; thus, doubling the size of a cell does not affect its voltage. This is seen in the fact that penlight dry cells and D-size flashlight batteries both have the same terminal voltage. The current available from a cell is determined by its geometry. In general, the larger the area of the electrodes, the larger the design current.

Batteries are, almost exclusively, series (head-to-tail) groups of cells. In this form, the voltages of each cell add to give the battery terminal voltage, but the current of the battery is the same as the current of each of its cells. Rarely, cells are placed in parallel to increase the current capacity, but differences of internal impedance among individual cells discourage this practice and make it impossible with some battery types. In any case, it should be avoided, unless specifically permitted by the manufacturer.

Batteries are often rated in ampere-hours (AH). However, this rating is not an invariant property of the design. If the current demanded of the battery is in excess of the design current, the ampere-hour capacity can be less than what the same battery would have delivered if drained at its design current. Fig. 3 shows this characteristic. Thus, a battery should be operated at or below its design current in order to obtain its published rating.

The amount or quantity of light times time is energy. Energy available from a battery is defined in terms of Watt-hours (WH), which are ampere-hours multiplied by terminal voltage. The best battery,

TABLE II. Mine Bulbs. A short representative list is given of mine bulbs. Not generally available, these bulbs must be purchased from mine equipment supply sources.

Bulb Number	Design Candlepower	Design Voltage	Design Current	Base Type	Life, Hours
BM 10 S	1.3	4.0	0.5	Miniature Screw	100
BM 17 G	1.75	4.0	0.55	Min. Screw	400
BM 20 G	2.9	4.0	0.8	Min. Screw	400
BM 26 G	3.6	3.7	1.0	D. C. Index	500
BM 26 D	. .	. .	. .	D. C. Index	
BM 28 G	3.8	4.0	1.0	Min. Screw	400
BM 28 H	5.0	4.0	1.25	Min. Screw	400
BM 75 A	3.6	4.0	1.0	Chand.	100
BM 30	4.9	4.0	1.2	D. C. Index	200
BM 30 A	3.9	4.0	1.0	D. C. Index	200

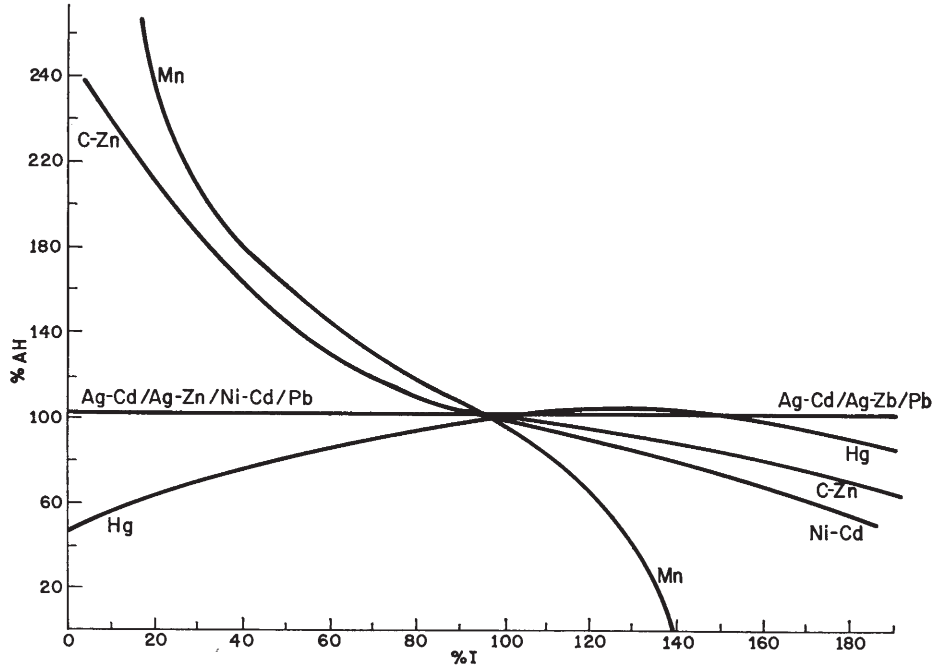

Figure 3. Available power (in percent of rated ampere-hours) as a function of steady current drawn (in percent of design current) for different types of batteries.

from a size standpoint, would have the largest energy density or energy per unit volume. This is usually expressed in Watt-hours per cubic inch, WH/in^3. Other significant characteristics are the energy per unit weight, expressed in Watt-hours per pound, WH/lb, and cost of usable energy contained, expressed in Watt–hours per dollar, WH/$.

Remember, in a battery consisting of a series of cells, that the AH rating of the *battery* is the *same* as the AH rating of each of its *cells*. Adding another cell will not change the AH rating of the battery, but the addition will increase the terminal voltage and hence the WH rating.

Batteries have even more interrelated parameters than lamps. Batteries are generally broken down into two broad classes: primary (one-shot) and secondary (rechargeable) batteries. This classification is actually vague in practice because every battery will accept some recharge, but the recharge of those classed as primary is never quite up to their original capacity. Hence, in their "recharged" state, primary batteries are seldom suitable for caving since batteries that are chosen or designed for cave applications make use of their full initial or design rating.

For those cells that can be recharged, a word is in order concerning charging. Cells on becoming fully charged, and most while charging, emit gas. The gas comes from the electrolysis of the water in the electrolyte. Most batteries which are designed for recharge have a vent for this gas to escape. For cave use, care must be taken that this vent is self-sealing and leakproof in use; the electrolytes of batteries, whether caustic or acid, can cause equipment damage and bad burns. Some newer batteries have a built-in capability to reabsorb the gas, provided it is not generated too fast. These batteries are advertised as sealed rechargeable batteries.

Some are actually sealed, but most have a pressure relief vent built in. Whether the batteries are sealed or vented, their capacity to handle the gas that is generated is limited. This, in turn, limits both the charging current and the amount of overcharge they can tolerate. Since the gassing rate goes up rapidly as the battery becomes fully charged, some cells will literally explode if charged too fast or overcharged. After the battery is fully charged, the charging current can be cut to a much smaller value (the trickle charge) and left flowing into the battery indefinitely in most cases. Both charging current and trickle charging current are functions of the battery's design and ability to handle internal heat and the gas generated. In no case should the manufacturer's recommendations be exceeded. Some batteries are permanently reduced in capacity, if not physically damaged, when they are overcharged, but others can tolerate considerable overcharge without loss. All vented cells need to have their liquid electrolyte level checked, because the gassing represents a loss of hydrogen and oxygen from the water of their electrolyte solution. Replenishment with pure distilled water is necessary to replace this loss. Less pure tap water will often damage or reduce the life of these cells.

All batteries will lose their power in time, even when not used. Since primary batteries are not recharged, the shelf life of their initial charge becomes very important. Battery action, being chemical, is affected by temperature. Although batteries vary in their shelf life characteristics, the shelf life of any battery can be greatly extended by storing it in a cool or cold place—the colder the better, short of freezing a liquid electrolyte. A deep freeze is recommended for the "dry cell" types. These batteries must be thoroughly thawed before use, however. The relationship between storage temperature and loss of battery life is illustrated in Fig. 4, which shows the time three types of batteries will retain their charge, if stored at various temperatures.

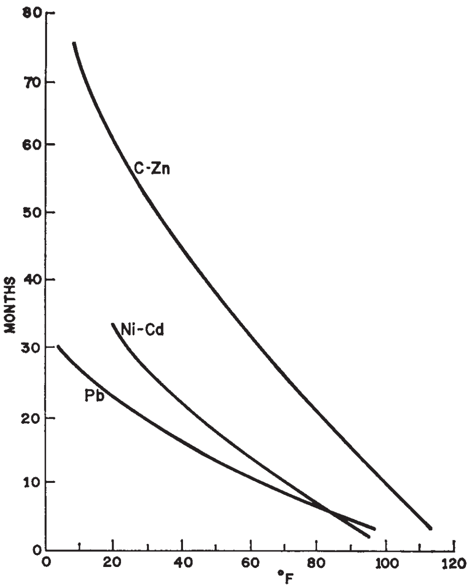

Figure 4. Battery shelf life as a function of storage temperature. The curves show how long C-Zn, Ni-Cd, and Pb batteries retain 50% of their charge when stored at various temperatures.

Batteries also vary in their tolerance to operating (as opposed to storage) temperatures. Those with a significantly lowered rating at U.S. cave temperatures (32°F – 70°F) can be derived from Fig. 5, which shows that all batteries lose efficiency at lower temperatures. Some lose so much as to be totally impractical at low temperatures, while the loss is not so severe with others. Some of the curves cross each other, which means that (other things being equal) the "best" choice will be different above and below the crossover.

The amount of current that can be taken from a battery in one continuous drain is usually less than if it is withdrawn in short intermittent loads. The cave battery must, of course, supply a non-interrupted light. All of the comparisons in this paper are based on a continuous discharge at 70°F, a manufacturers' standard for ratings. Cavers must modify this by reference to Fig. 5 for their local cave temperature.

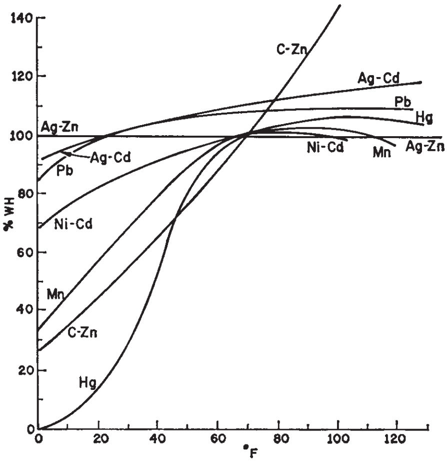

Figure 5. Available capacity (in percent of rated watt-hours) for various types of batteries as a function of the environmental temperature in which the battery is operated.

The terminal voltages of various batteries behave differently during discharge. Some supply extremely steady voltages until almost completely discharged, when they suddenly go dead; while in others the output drops continually towards zero. These characteristics are shown in Fig. 6. For comparison purposes, a battery will be considered at the end of its useful life when its voltage, under a constant load, has reached 80% of its fully charged or steady state voltage. All voltages must be measured under load, because even "dead" batteries often exhibit high open-circuit potential. An advantage of a steady level voltage during discharge is a steady non-dimming light — uniform illumination throughout the cave trip. On the other hand, a dropping voltage gives warning of the state of the battery and supplies some (although weak) light for some time after the "dead" point (by definition) is reached.

The following primary batteries will be compared:

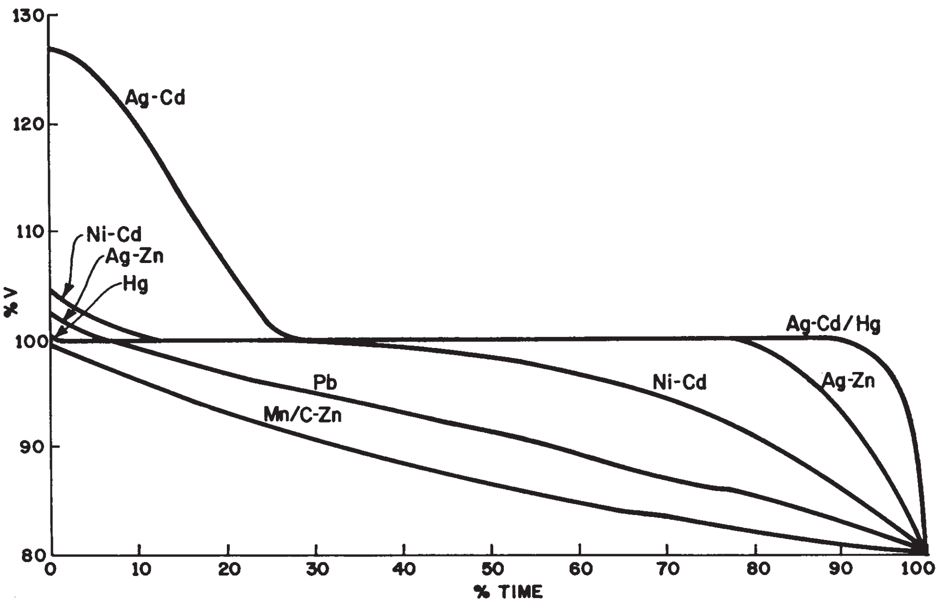

Figure 6. Voltage (in percent of rated voltage) as a function of time for various types of batteries while discharging under a steady load to 80% of rated voltage (defined as a dead battery).

1. Carbon(C-Zn). Variously called dry cell, common flashlight battery, carbon-zinc battery, and LeClanche cell. It uses carbon and zinc electrodes in an alkaline paste electrolyte.

2. Manganese(Mn). Also called alkaline and energizer. It uses manganese oxide and zinc electrodes and an alkaline paste electrolyte.

3. Mercury(Hg). Known simply as a mercury battery. It is composed of mercuric oxide and zinc electrodes and an alkaline paste electrolyte.

Secondary batteries to be compared are:

1. Silvercell(Ag-Zn). This battery uses silver oxide and zinc electrodes in a potassium hydroxide solution (alkaline) electrolyte.

2. Silcad(Ag-Cd). This battery comprises silver oxide and cadmium electrodes in a potassium hydroxide solution electrolyte.

3. Nicad(Ni-Cd). The nickel oxide and cadmium electrodes are placed in a potassium hydroxide solution electrolyte in this battery.

4. Edison(Fe). The old Edison cell uses iron and nickel electrodes in a potassium hydroxide solution electrolyte.

5. Lead-acid(Pb). The common auto battery uses two lead electrodes in a liquid electrolyte of sulfuric acid. When charged, one electrode will be lead peroxide.

The results of these comparisons are tabulated in Tables III and IV. Included for comparison is the data on a carbide lamp under the following assumptions: it will burn 2 hours on one charge emitting 2.0 cp and use 1.5 oz. of water and 1.8 in^3 of large cube carbide (purchase price is $1.00 for 2 lb (54.7 in^3) of carbide). These data were taken from personal measurements and observations. In all cases, including the carbide, the cost of the lamp itself is excluded. The bulk (WH/in^3) and weight (WH/lb) figures are based on a single charge, since this is the useful comparison for cave use; however, the WH/$ is based

TABLE III. Primary Battery Comparisons at 4 representative load currents for D size cells. Note that in the WH/$ column there is a cross-over of value between the Mn and Hg batteries, depending upon current drawn. The Ni-Cd and Ag-Zn D-size cells are shown as well as carbide for comparison. Zero values shown are not exactly zero but so small as to be practically zero.

Type	Current Drain	Hours	WH/in ^{3}	WH/lb	WH/$	Cost of Battery ($)
C-Zn	0.15	15	0.975	1.39	1.95	0.15
	0.30	3	0.390	0.56	0.78	
	0.50	0.8	0.017	0.25	0.35	
	1.00	0	0	0	0	
Mn	0.15	42	2.57	27.3	14.90	0.55
	0.30	12	1.47	15.7	8.55	
	0.50	8	0.16	1.7	0.95	
	1.00	0	0	0	0	
Hg	0.15	80	5.32	39.4	4.8	3.00
	0.30	48	6.36	47.1	5.7	
	0.50	29	6.44	48.7	5.8	
	1.00	8	3.55	26.3	3.1	
Ni-Cd	1.00	4	1.46	14.05	176	5.00
Ag-Zn	1.00	5.3	3.00	32	0.84	9.60
Carbide	. . .	2	0.78	23.3	1900	0.023

TABLE IV **Secondary Battery Comparisons. The wide tolerances are due to great variations among manufacturers. With these variations, any one could outperform any other one in a specific case. Carbide is included for comparison.**

Type	WH/in ^{3}	WH/lb	WH/$	Expected Cycles	Cost/ 10AH Cell
Ni-Cd	1.2±0.6	11±3	2000±500	2000±500	$17.00
Pb	0.9±0.4	11±3	640±130	300±100	7.00
Fe	0.7±0.2	10.6±0.5	1800±1100	1500±200	9.00
Ag-Cd	1.9±0.6	35±25	3300±1100	2000±500	25.00
Ag-Zn	2.7±0.3	41±10	200±200	100±50	25.00
Carbide	0.78	23.3	1900	....	....

on *all* of the hours to be used, that is, hours per charge times number of recharges expected in the life of the battery. Costs are based on new batteries at current retail battery prices. Surplus, wholesale, or used prices may alter the WH/$ significantly, just as bulk purchases of carbide can alter the figure given. Inflation can also alter this figure; however, all data were taken at the same time so that their relative values ought to be valid.

The tables show that the utility of the carbon dry cell is increased enormously at low drains; thus, it should be used only in low candlepower applications. The Silcad battery is the cheapest to operate over the life of the battery. The mercury battery is the lightest and the least bulky. Since cycle life varies among manufacturers, the WH/$ of the rechargeable batteries is subject to wide variations. In general the Silcad, lead-acid, Edison, and nicad batteries can be considered competitive with carbide in cost and weight, in the long run, and are less bulky. Table V gives a cross index of manufacturer's numbers of several common types of batteries.

Primary Cells

Table IV clearly indicates that primary cells are out-classed by both secondary cells and carbide in value returned for dollars invested. The sole advantages of primary batteries are low initial cost and trouble-free operation.

1. Carbon. This is probably the most used and least understood (quantitatively) of the batteries. As can be seen from Fig. 3 and Table IV, the use of an ampere hour rating is meaningless because one can obtain a disproportionally long life for small discharge currents.

The shelf life of carbon dry cells is comparatively short at room temperatures but can be very long in a deep freeze, as can be seen in Fig. 4. This battery also loses power at low operating temperatures, as shown in Fig. 5. When used at 0°F, for example, they are practically useless; and when used at 32°F, they give only a little over half of the published life. As shown in Fig. 6, cell voltage falls off linearly with use from the 1.5 volts per cell "new" to the 1.2 volt "dead" point. After this, the battery will continue to supply power at a reduced output for a long time, which is a sort of "safety measure" for caving. Among the nonrechargeable batteries, the carbon dry cell offers least power per dollar. Figure 7 shows the time an average, industrial-type, D-size standard flashlight battery will supply a given current, although there are wide variations among brands. Most manufacturers make several quality D cells, with various ratings. The tables are based on the best of the "industrial" grade cells (see Table III).

2. Manganese. The principal outstanding properties of the alkaline drycell are its higher ratings than the carbon cell; this property makes it attractive. These ratings, however, are extremely dependent on discharge current. Table III and Fig. 7 show the life expectancy for various drains on the standard D-size cell. As the high slope

TABLE V. Cross Index of Manufacturers' Numbers for Common Industrial Grade Batteries.

Type	C-Zn (Le Clanche)	C-Zn (L. C.)	C-Zn (L. C.)	Mn. (Alkaline)	Hg (Mercury)	Ni-Cd (Nicad)	Ni-Cd (Nicad)
Common Name	D-Size Flashlight	Lantern	Radarlite	D-Size Flashlight	D-Size Flashlight	D-Size Flashlight	6 AH Rectangular
Dimensions, inches	1.25 x 2.25	2⅝ x 2⅝ x 4 3/16	5⅜ x 2⅞ x 5	1.25 x 2.25	1.25 x 2.25	1.25 x 2.25	2 x 1¾ x 3 11/16
Voltage	1.5	6	6	1.5	1.3	1.2	1.2
NEDA	13	925	918	13A	....	....	....
Burgess	210	F4BP	TW-1	AL-2	HG42R	CD 10	CD 105
GE	....	....	....	....	....	41B004AA05	42B007AA01
Eveready	1050	2746	731	E95	E42N	N56	N76
RCA	VS336	VS040S	VS317	VS1336	....	....	....
Bright Star	10MC	460S	158	7520	....	8012	8383
Mallory	M13X	M915	M918	MN1300	RM42R	....	....
Ray-O-Vac	3LP	941SC	918	....	....	....	....
Sears	4663	4667	4707	4653	....	....	....
Wards	13259	13257	13274	13267	....	....	....
Wizard	7D8113	7D8915	7D8918	7D7843	....	....	....
Sonotone	....	....	....	....	....	WS-103	5BL 420
Gulton	....	....	....	....	....	R-400	....
Vidar	VT-12	....	....	....	....	....	....
Gould	....	....	....	....	....	4.0SCB	P6

NOTE: Manufacturers often sell many differently rated batteries of the same size. Those listed above are the highest rated for their size.

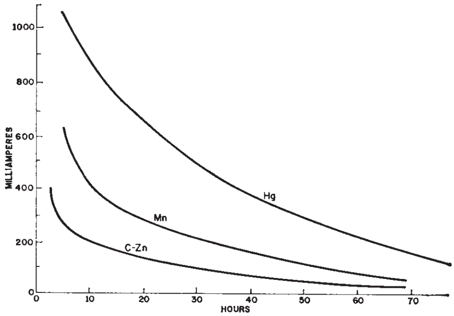

Figure 7. Ratings of three types of dry cell batteries. These curves show the length of time for which dry cells can supply a given current before reaching the 80% voltage representing a dead battery.

in Fig. 3 shows, the D cell has a particularly poor life at high drain rates, although, paradoxically, it can supply higher currents for short times due to its lower internal impedance. It is so poor at high currents that at drains of 0.5 A and higher—even at 20°F, where its efficiency is 60% compared to a mere 14% for the Hg battery, it is still outclassed by the Hg battery! It stands between the carbon and mercury batteries in other characteristics. It is a possible choice for cavers who want light from nonrechargeable batteries but who cannot afford the initial high cost of the mercury battery or who design rigs with low current drains, where Fig. 3 shows it alone excels. Its cell terminal voltage is 1.5 volts and, like the carbon cell, tends to drop linearly with use to its 1.2-volt "dead" point. (see Fig. 5).

3. Mercury. This battery is noted for its high energy density. For this reason, it is very popular as a transistor radio power supply and in electric watches. As seen in Fig. 6, terminal voltage is nearly constant throughout its useful life, which means the battery performs well for a long time then suddenly goes dead. The battery has two drawbacks; it is very, very sensitive to temperature and it has a high initial cost, although in the long run it is the most economical of the dry cell types at most practical currents. At 32°F and lower, the battery is practically useless, and for drains above 0.5 ampere, the loss of capacity is enough to make these applications questionable. The mercury battery still has its caving use, however, in southern caves or on expeditions to remote areas where its small size and extremely long life outweigh its high cost. Figure 7 shows the expected life vs current drain. Its cell terminal voltage is 1.35 volts. Even though the 80% or dead voltage is 1.1 volts, due to its flat voltage characteristic, the terminal potential will be close to 1.3 volts throughout use.

Secondary Cells

Any of the rechargeable batteries offer an economic advantage over the primary cells. A comparison of the various types is given in Table IV.

1. Silvercell. Among the rechargeable batteries, this version packages the greatest energy per weight and volume. It has a small recharge cycle life (20 to 100 cycles), however, which coupled with its very high initial cost keeps the energy per dollar figure low—too low to compete with the other types.

The terminal voltage is essentially unchanging at 1.5 volts until it plummets to the 1.2 volt dead point. The battery is also tolerant of a wide range of current drains; thus, the AH rating is true for both low and high drains. This rating is also moderately independent of temperature. Operating time can be obtained simply by dividing the AH rating by the current drain. The Silvercell is, however, sensitive to overcharge.

2. Silcad. Unlike the silver-zinc battery, the silver-cadmium battery is relatively insensitive to overcharge although the charging rate must be controlled. The terminal voltage rises abruptly to 2.0 volts at full charge, which makes a self-regulating charger both simple and feasible. The Silcad also has a much larger cycle life (up to 2000 cycles). This latter feature, despite the very high initial cost, makes the energy source economical. Its terminal voltage,

again flat, is 1.1 volts. This battery, too, is insensitive to current drain with respect to rating, making the AH rating a valid number to use in calculating battery life per charge.

3. Nicad. These are the most popular rechargeable flashlight batteries. They are also used in many cordless home appliances such as toothbrushes, razors, etc. In the sealed version, they are sensitive to too high a charging rate. The nicad is moderately sensitive to current drain, the capacity falling to 80% at twice the design drain. Figure 3 illustrates this feature. However, AH ratings are widely used. The discharge voltage characteristics are shown in Fig. 6. Its cycle life is higher still than the other two batteries discussed and its initial cost is also lower.

Another advantage of the Ni-Cd cell is its ability to accept a rapid recharge at high currents. For cave divers or those who wish to cave again immediately, this can be important. However, if the battery is being recharged at high currents, it must be vented and carefully checked to see that its temperature does not rise significantly. The recharge AH should be from 1.2 to 1.5 times the discharge AH. Normally, recharging at 1.5 times the discharge current and for the same time as discharged is convenient and makes calculations easy. Nicad batteries can remain on a low trickle charge almost indefinitely once charged.

The electrolyte takes no part in the chemical changes of charge or discharge but acts merely as a carrier. As a result, the liquid of a charged or discharged cell will have the same specific gravity. Its state of charge cannot be measured with a hygrometer; in fact, it can't be measured at all, except by discharging the cell. Memory or keeping records of the time used is necessary in order to recharge properly. This constant specific gravity is true of all of the cells using a solution of potassium hydroxide as an electrolyte.

All things considered, the nicad battery falls well within the practical limits for cave use. Although it may be slightly outclassed by Silcad (and sometimes by lead and Edison cells) in certain cases, it is often obtainable at much less than retail listed cost and is, therefore, a good caver's choice. There is a Japanese commercial miners lamp and battery that uses nicad cells.

The nicads are best stored either on trickle charge or completely discharged. Caution: a battery of nicad cells should never be completely discharged while in series. Permanent damage to one or more of the cells may result. They should be totally discharged only as individual cells. In a series, if one cell goes dead sooner than the others, they will charge it in the reverse direction while completing their discharge. This reverse charging can permanently damage that cell of the battery.

4. Edison. The principal advantage of the iron alkaline battery is its toughness. The Edison cell can stand a great deal of both physical and electrical abuse (shorts, complete discharge, overcharge, etc.). For this reason, it was once the common commercial choice for miners' headlamps. Edison batteries by themselves are not readily available in a size suitable for caving, except these miners batteries. Miners battery-lamp combinations, however, are on the market. A disadvantage is the necessity for a large vent while recharging. Since this must be sealed during use, the mechanism, usually lid actuated, is subject to malfunction and must be carefully maintained to prevent dangerous leaks. The terminal voltage of a cell is 1.2 volts. The battery is best stored discharged; it should be charged just before use. There is no harm in a series battery total discharge for this type.

5. Lead-acid. This is the common auto battery. At least two commercial miners batteries are of the lead-acid type; they have an automatic vent mechanism rather than a lid-actuated one that seems to be slightly more reliable. The lead-acid battery, however, is less rugged electrically. The battery must not be allowed to sit idle while discharged; permanent loss of capacity results. It can be stored indefinitely, however, if its charge is maintained by a trickle charger.

The sulfuric acid solution electrolyte in this battery plays an active role in the battery charging chemistry. As a result, the specific gravity of the electrolyte is an accurate indication of the charge status of a cell. The cell terminal voltage is the highest of those compared—2 volts; its behavior during discharge, shown in Fig. 6, is an almost linear drop in voltage. A new sealed version of the lead-acid battery is now commercially available. This latter feature, taken with its comparatively high energy density and low purchase price, makes it a possible choice for cavers.

New Batteries

There are several new batteries under active development, but since most of their characteristics are not available they will merely be described briefly.

1. The magnesium-silverchloride cell is said to deliver 60 WH/lb and 4.5 WH/in^3. It is a primary battery that is stored dry and activated with salt water.

2. The magnesium-cuprous-chloride cell is similar. These cells have an exceptionally long shelf life but must be used fairly soon after activating. They might be a good choice for a rescue squad that needs lights that can be made ready to go in a moment but does not want to be plagued with replacing cells due to shelf life.

3. A mercuric oxide-cadmium cell is also still in the development stage. It is a primary dry cell type that seems to possess the high energy density of the standard mercury battery but will tolerate a greater discharge rate. This looks like one to watch if it can be made available at competitive costs.

4. The lithium cells being developed for electric autos theoretically have the highest power density of all, if they can be perfected.

5. Zinc-air batteries require pressurized air, an air pump, or open access to the air and are thus economical only in sizes too big to be of help to cavers at present. Also, in present versions, there is a great spill hazard of the electrolyte because of the necessary air access.

Exotic Power Sources

Several additional means are available to convert chemical or heat energy to electrical energy. Fuel cells, atomic batteries, and thermionic units have all been used in special cases with good results. However, in the range of energy needed by cavers, these systems are not practical, nor do they seem to be developing in that direction.

There is one new development that converts chemical energy directly into light. Two chemicals are kept separated in a sealed glass vial. Shaking the vial ruptures the seal and mixes the chemicals in the vial. The mixture is then highly luminous for several hours. This system seems to have a very long storage life and an exceedingly small bulk. It might very well be used as an emergency extra light source, except that the caver must be careful not to accidently activate it. In this application, its reliability and rare use would offset a high cost.

Lamp-Battery Combinations

A lamp should be hard-hat mounted, in front, and aimed at floor level about 15 ft ahead. The need for keeping the hands free is overwhelming in speleology. A belt-mounted lamp can be shadowed by the arms as well as always pointing in the wrong direction.

Two principal ways of carrying the lamp battery are possible: mount the battery on the hat and avoid an entangling cord, or mount a large battery on a waist belt and obtain a longer burning time. If the former method is chosen, the battery is usually mounted on the rear of the hat where it serves the additional function of lamp counterweight. A practical limit of 10 in^3 shows that few batteries are suitable for this purpose. A good practical limit for the belt-carried battery is about 100 in^3. A belt-carried battery can be slipped to various parts of the waist easily; and, of course, the cord should be routed to the rear of the hat and attached there.

The cord should either be very rugged (like the mine rigs) so that it can literally lift the battery without damage, or it should have a friction, pull-apart plug that can be easily reinserted.

For caving use, power levels usually stay at or below 12 volts. At these low voltages, no waterproofing need be undertaken. Exposed low-voltage wiring will work perfectly well submerged in cave water, although long term corrosion can damage equipment if it is stored wet. There is no shock hazard below about 24 volts.

Ideally, the battery terminal voltage (during use) should match the operating voltage of the bulb picked to give the desired bulb brilliance and life expectancy. The lamp current drawn at this operating potential should match (or be less than) the design current of the battery. Only if both of these two criteria are satisfied can full advantage be taken of the energy density of the battery. In practice, matching both criteria is impossible and one parameter must be compromised.

In the lamp, power consumed equals operating voltage times current drawn.

$$P_O = E_O I_O \qquad (1)$$

E_O = operating potential (volts)

I_O = operating current (amperes)

P_O = operating power (watts)

Equation (1) gives the actual power consumed. Assuming I_O is close to the design current for the battery chosen and the power density is known in WH/in^3 for the battery, the size battery for a given time of light can be calculated from equation (2).

$$V = P_O \times T_O/(WH/in^3) \qquad (2)$$

where:

T_O = operating time (hours)

V = volume of battery ($inches^3$)

The battery rating in ampere hours can be calculated from equation (3).

$$AH_O = I_O \times T_O \qquad (3)$$

where:

AH_O = battery AH actually available

Here is a practical example, taken from a commercially available combination: A No. 4546 bulb is used with a Burgess TW-1 battery. The terminal potential of this battery is 6 volts. The bulb is rated: $E_d = 4.7$ volts, $I_d = 0.5$ amperes, and $L_d = 100$ hrs, where the subscript, d, indicates design values.

$E_d I_d = P_d = 4.7 \times .5 = 2.35$ watts. From Fig. 1, this gives an approximate rated candlepower of about 1.5 cp. However, the battery has a terminal voltage of 6 volts, which will be the operating potential.

$$\frac{E_O}{E_d} \times 100 = \frac{6.0}{4.7} \times 100 = 128\% \text{ operating potential}$$

over design for the bulb.

From Fig. 2 operation at 128% potential gives 120% current, 230% cp, and 3% design life. Thus, the actual operating conditions with a fresh battery are:

$E_O = 6$ volts, $I_O = 0.6$ amperes, $P_O = 3.6$ watts, $CP_O = 3.45$ cp, and $L_O = 3$ hrs.

At the end of useful life (4.8 volts) these conditions have become:

$E_O = 4.8$ volts, $I_O = .5$ amperes, $P_O = 2.25$ watts, $CP_O = 1.5$ cp, and $L_O = 100$ hrs.

The expected average values from this lamp-battery combination are:

$E_O = 5.4$ volts, $I_O = 0.55$ amperes, $P_O = 3$ watts, $CP_O = 2.47$ cp, and $L_O = 50$ hrs.

Using the manufacturer's curves for this battery, at 0.55 A, a continuous useful life of about 5 hours at 2.47 cp can be expected from a new battery, when used at 70° F (when used at 32°F, don't count on over 2½ hours).

The lower limit for any practical combination will be fixed by the amount of light needed to see by in exploring an "average" cave. Although in an emergency, escape is possible with as little as 1/8 cp, 1/3 cp is considered a minimum working brilliance and about 5 hours as a minimum time (plus one spare battery to reach 10 hours). The maximum is determined solely by the caver's physical endurance in carrying weight and bulk, but a working maximum is probably a bulk of 100 in^3.

Within these contraints, one can choose, as examples:

1. A *long-lived* combination of a No. 502 bulb with 4 D-size Hg batteries of 12.8 in^3 which gives *80* hours of 0.9 cp light at only 4.8 WH/$.

2. *A very brilliant* light of a No. 965 bulb with a MF-2 (Exide) sealed lead acid battery of 67 in^3, which gives 11 hours of *10.0 cp* at 768 WH/$.

3. *An economical* rig of the Honda miners cap lamp and nicad battery (two 15-AH cells) of 100 in^3, which gives 15 hours of 1.5 cp at *2500 WH/$.*

4. *A small bulk* of a No. 35 bulb with 2 D-size Hg batteries of *6.4* in^3 which gives 10 hours of 1.30 cp, but at only 6 WH/$.

Summary

Theoretically, the nicad or, perhaps, the Silcad battery is the most economical battery, and the mercury battery is best for small bulk, but picking an "ideal" caving lamp or battery is impossible because the optimum design is heavily dependent on such personal choices as length of burning time vs brilliance of light; both of these vs size of battery; all of these vs ruggedness; etc. The length of the "average" caving trip to be undertaken determines the burning time, for instance. Commercial miners battery and lamp combinations make excellent caving choices for some caves, but, since they are designed for 8-hour shift use (with some safety margin), these combinations will be unsuitable for other cavers. They are designed for rugged use, however, and mining firms also demand economy and long life, although they can usually afford a higher initial investment for a better long-term return on their dollar.

Three equations sum up the relationships of the various parameters.

$$WH_d = AH/cell \times V_d/cell \times N \qquad (4)$$

The rating of a battery (in watt-hours) is equal to the current rating of a cell (in ampere-hours) times the closed circuit potential of a cell at the rated current (in volts) times the number of cells in the battery. Remember, in secondary cells the current rating is mostly independent of the current drawn; but in primary cells, the current rating must be calculated from a curve, characteristic of the cell, as a function of the current drawn from the battery. (See Fig. 7.)

$$T_O = \frac{WH}{V \times A} \qquad (5)$$

Time of useful light available (in hours) is equal to the battery rating (in watt-hours) divided by the product of the current actually drawn (in amperes) times the terminal potential (in volts).

$$CP_O = \frac{WH_d}{T_O} K_L \qquad (6)$$

$$\text{where } K_L = (0.7 \frac{L\text{-}500}{5000})$$

The brilliance of the light available (in candlepower) equals the battery rating (in watt-hours) divided by the useful time of light (in hours) times the factor K_L, which is a function of the life of the bulb, after correction from Fig. 2 for the actual operating point. It is expressed as L_O (in hours) and varies from about 0.5 (rugged) to 0.7 (fragile), with 0.6 being a good average.

The comparison tables, discharge curves, and descriptive characteristics can help a caver choose those features best suited to his needs. An exact understanding of the actual operating point of the battery-lamp combination will prevent either disappointment or compromising the wrong factor.

Technology is moving very rapidly in the refinement and development of batteries. All of the data in this paper are very likely soon to become obsolete. Therefore, close attention must be paid to new battery discoveries and products; the discussions of this paper will give an indication of which parameters are the important ones for cavers to watch.

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Human Biological Rhythms During and After Several Months of Isolation Underground in Natural Caves

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ABSTRACT

Speleologists have contributed invaluable data on human circadian and menstrual rhythms, demonstrating the persistence of these bioperiodicities over spans of several months of complete solo isolation from any or all known time cues. Under conditions of such solo isolation, including the absence of any direct interpersonal relations, statistically significant changes in frequency are demonstrated for both the circadian system and the menstrual cycle. The desynchronization of the circadian sleep-wakefulness rhythm from a precise 24-hour schedule occurs as a statistically significant phenomenon even in the case of a group composed of members interacting with each other but isolated in a cave from their habitual societal setting.

In separate, but concurrent, experiments two speleologists spent periods of three and four months, respectively, living in a cave in complete isolation from all external time cues. During this span observations on several periodic physiological functions, such as sleep-wakefulness, rectal temperature, urine volume, and excretion of potassium and 17-hydroxycorticosteroids were made. The data were subjected to a spectral analysis by computer techniques. Changes in various cyclic functions, interactions between different functions, and resynchronization at the end of the study are discussed. Comparisons are made to an earlier study involving time-disruption due to intercontinental flights and to human isolation in a laboratory apartment. Other studies of cave isolation are summarized and compared with the two experiments described. Justification for isolation studies in caves and for microscopic spectral analysis of the data is presented. The studies reveal that cyclical variations in environmental and social factors do not bring about human bioperiodic phenomena but are able to synchronize these bioperiodicities. Internal circadian and other time relations mapped during solo and group isolation provide a reference standard for assessing the effect upon human time structure of the many societal influences to which individuals or groups are exposed in our habitual way of life.

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Background on Biological Rhythms

In man, as in many other forms of life, a spectrum of rhythms can be objectively observed. Gross motor activity, sleep-wakefulness, and body core temperature exhibit rhythms as do specialized physiologic functions such as those of the brain, heart, lung, adrenal and other glands, and even cellular and subcellular activity (Kleitman, 1965; Reinberg and Ghata, 1965; Sollberger, 1965; Mills, 1966a; Halberg, 1960, 1962, 1964a, and 1969; Halberg *et al.*, 1959; Nelson and Halberg, 1966; Halberg and Reinberg, 1967; Bünning, 1964). Although recognized for several centuries, the functional variations in man have been intensively studied only for the last 20 years. Such investigation is in fact indispensable to a better knowledge of biology, including both human physiology in health, on regular as well as odd routines (such as shift-work or adjustments after transmeridian flights), and chronopathology, the study of rhythm alterations which may connote disease.

Under ordinary conditions of life on the surface of the earth, daily, yearly, and other variations are encountered in a number of environmental factors influencing the human organism. The alternation of day and night, changes in daily photofraction, time schedules connected with social life, and variations in environmental temperature are but a few pertinent examples. Through evolution the period of some of these environmental variations has been acquired by man's biologic time structure in the form of endogenous or internal rhythms. The endogenous rhythms are synchronized by the external variations or exogenous cycles [called synchronizers (Halberg *et al.*, 1954)].

It should be emphasized that synchronizers do not "create" physiologic time; rather than determining the biorhythms (which persist in their absence), they only modify certain rhythm characteristics, such as the period and the acrophase (the timing of a cycle). Most investigators today recognize that many of the human biological rhythms, as well as those of other animals and of plants, are not newly acquired by each individual in each generation, but exhibit several seemingly innate features (Reinberg and Ghata, 1965; Halberg, 1960 and 1962; Halberg *et al.*, 1959; Bünning, 1964; Hildebrandt, 1961).

To study an organism's rhythms, one may manipulate internal factors, e. g., by removing a gland or replacing its hormones (Halberg *et al.*, 1959). In addition, one attempts to find out (if not to control) the nature and period (if any) of influencers, modulators, or synchronizers as well as the mode of synchronization of the organism's rhythms (Halberg, 1969). One further utilizes physical, chemical, or other methods of measurement properly adjusted to the experimental conditions and the nature of the physiologic functions studied. Unfortunately, some reports on rhythms have been limited in value by the absence of reference to a standardized methodology, including the variability of the technique *per se,* and by the failure to provide even an "elementary" account of the conditions of experiment or observation.

A "leap forward" since 1960 in knowledge of biologic rhythms is associated with the exploitation on a larger scale of new possibilities for the analysis of the raw experimental values obtained as a function of time. Earlier, the prevailing custom was merely to plot—on so-called chronograms—the experimental values according to the time when they were obtained and, possibly, to submit them to a conventional statistical analysis. The interpretation of a chronogram remained in large part subjective and therefore relatively imprecise. The development of specially designed electronic computer programs has greatly facilitated the analysis of rhythms and given a more objective interpretation to the results. (Halberg and Panofsky, 1961; Panofsky and Halberg, 1961; Halberg, 1964b, 1965, and 1966; Halberg *et al.*, 1960, 1965a, 1967, and in press; Haus and Halberg, 1970). Thus, by the fit of one or several cosine functions, one can characterize cyclic variations by several parameters for each rhythm. Moreover, the analysis of an appropriately-long time series of a physiologic variable, such as rectal temperature, blood pressure, or the urinary excretion of several hormonal metabolites, usually reveals the occurrence of several rhythms with different periods.

There are several parameters which are used to describe cyclic variations and which will be mentioned frequently throughout this article. The length of time taken to complete one full cycle is called the period, τ. Sometimes it is more convenient to refer to the frequency, f, which is simply $1/\tau$ and describes the number of cycles in a given time interval. Another important characteristic is the acrophase, ϕ, determined as the lag from a phase reference, such as midnight for circadian rhythms, to the peak (in the best-fitting curve used to approximate the rhythm). This describes the estimated time of occurrence of the maximum in the cyclic variation, as, for example, the hour of maximum temperature in the about-daily variation of body temperature. Acrophase is commonly measured in degrees, with 360 degrees representing a full period τ. Thus people living in Eastern and Pacific time zones will have a 3-hour difference in the phase of their 24-hr synchronized cycles or an acrophase difference of 45 degrees (3 hours out of 24 equals 45 degrees out of 360). The absolute difference between the maximum and the mean value of a cyclically-varying parameter approximating the rhythm is termed the amplitude A. The average value which the parameter has during the cycle is called the rhythm-adjusted mean or mesor, M.

Rhythms with a period τ of about 24 hours ($\pm$ 4 h), called *circadian* (from *circa* = about and *dies* = day), have been revealed as being particularly prominent. For a consideration of the broader spectrum of rhythms, it is convenient to refer to frequency by analogy to physics. Rhythms with a frequency higher than 1 cycle in 20 hours —between 1 cycle in 0.5 h and 1 cycle in 19.9 h—are called *ultradian*. A rhythm is called *infradian* when its frequency is lower than 1 cycle in 28 h but higher than 1 cycle in 6 days. Ultradian, circadian, and infradian rhythms belong to the biologic spectral domain of *medial frequency rhythms* (Halberg, *et al.,* 1965a; Halberg and Reinberg, 1967; Haus and Halberg, 1970). These domains are illustrated in Table 1.

The spectral analysis of variations by computer estimates the period, the mesor, the amplitude, and the acrophase, *inter alia,* of any infradian, circadian, and/or ultradian rhythms in a given physiologic function (Halberg *et al.,* 1965a; Halberg, 1964b and 1965). What is particularly interesting, it also assesses the acrophase relations of different biologic rhythms with the same frequency—in particular of circadian rhythms (Halberg *et al.,* 1967; Haus and Halberg, 1970). Current programs make possible the objective analysis of serial data collected at unequal time intervals. Such programs to analyze unequidistant data were originally developed for a study of human isolation, following a study of the effects of phase-shifts of routine as a result of transmeridian flights (Figs. 1 and 2). While such programs are indispensable for work on conscious subjects deprived of all temporal clues in isolation experiments, these same programs also render practical the self-measurement of rhythms [autorhythmometry (AR)] for the assessment of health (Halberg *et al.,* 1972).

From AR, as well as other studies on healthy human adults, the human time structure can be mapped in each spectral domain. Among other qualified results, acrophase charts thus depict a set of physiologic functions. An aim of chronobiologic endeavors is to study the organism's time structure and its alteration or persistence under various experimental or pathologic conditions. Between the conclusions drawn from the examination of a time plot of serial data and those drawn from results of special programs for electronic analysis, there may be a difference as great as that between the examination of a tissue by the naked eye and its examination through a microscope (Halberg, 1966).

Why Autorhythmometry?

There are several reasons to couple a technique of repeated self-measurement with the analysis of any predictable rhythmic

TABLE 1. Illustrative Spectrum of Rhythms

DOMAIN:*	HIGH FREQUENCY $\tau < 0.5h$	MEDIAL FREQUENCY $0.5h < \tau < 6d$	LOW FREQUENCY $\tau > 6d$
REGIONS:	$\tau \sim 0.1$ s $\tau \sim 1$ s et cetera	ULTRADIAN ($0.5h < \tau < 20h$) CIRCADIAN ($20h < \tau < 28h$) INFRADIAN ($28h < \tau < 6d$)	CIRCASEPTAN ($\tau \sim 7d$) CIRCAVIGINTAN ($\tau \sim 20d$) CIRCATRIGINTAN ($\tau \sim 30d$) CIRCANNUAL ($\tau \sim 1$ yr)
RHYTHMS in:	Electroencephalogram Electrocardiogram Respiration	Rest-Activity Sleep-wakefulness Responses to drugs Blood constituents Urinary variables Metabolic processes, generally	Menstruation 17-Ketosteroid excretion with spectral components in all regions indicated above and in other domains

* Domains and regions [named according to frequency (f) criteria] delineated according to reciprocal f, i. e., period (τ) of function approximating rhythm. s = second, h = hour, d = day.

Several variables examined thus far exhibit statistically significant components in several spectral domains.

variation. A first one relates to the maintenance of health. Medically evaluated vital signs, such as temperature and blood pressure, are now known to be variable rather than constant. Characteristics of spontaneous and reactive changes in such rhythmic physiologic functions, once they are objectively quantified, assess through performance the state of one's health. Results of prior AR can provide physicians with standards of reference for each individual with whom they deal in the course of treating sickness or injury. The following considerations are pertinent:

A. Unquestionably, repeated measurements made over appropriate spans of time provide a solid and individually pertinent data base, whether or not a portion of their variability can be identified as being predictable (notably rhythmic) rather than random. By comparison, only limited information about the individual is available from the conventional single or few measurements made in the physiology laboratory or by a physician or other health sciences personnel during the usually short spans of interaction with the subject in the hospital, the office, or home.

B. As already noted, the analysis of time series by modern computer methods improves the kind as well as the extent of the information base, in that it yields information on rhythms and other characteristics rather than on time-unqualified samples.

C. Self-measurements not only provide more extensive data on rhythms with more than one frequency but they do so under conditions of "ordinary" life. Such circumstances resemble more closely the person's usual milieu and hence may complement the assessment of a given individual in the setting of a laboratory, hospital, or office. Eventually, minimal sampling requirements will have to be established for each practical purpose visualized—health monitoring or some other. Until this goal is reached, unusually long and thoroughly collected time series provide unique reference standards for more modest sampling and for the study of special physiologic problems.

D. Authorhythmometry is practical as well as economical. It is achieved without hospitalizing the individual or even seriously restricting his life style.

E. Autorhythmometry represents a remarkable service not only to assess health but also to treat disease. With AR available, the family physician can be assisted by his patients in improving the information base concerning them and thus the quality of their care. Using their self-measurements, he can cease to depend upon a single time-unqualified, and hence unrepresentative, measurement of such variables as blood pressure, heart rate, or body temperature when he treats, for example, blood-pressure elevation. The interpretation of single casually or "basically" recorded vital signs in relation to a crudely measured population "normal range" can be replaced by the scrutiny of the abnormality or normalcy of a time series of vital-sign measurements or even a single value in relation to temporally-qualified reference standards appropriate to an individual as well as to his cohort.

Apart from any and all medical endeavors—preventive or curative—AR has educational merit. It represents a truly cross-disciplinary endeavor. Thus, AR uses measurement procedures that rely on physics (as in the evaluation of temperature or blood pressure), chemistry (determination of urinary constituents), psychology (assessment of physical and mental performance), and computer science and mathematics (in data preparation for analyses, execution of computational checks, and display of results). The educational value of the teaching of chronobiology in relation to AR must be judged by what this topic would displace in the now-existing curriculum; certainly one should replace those materials on homeostasis which imply or state that many body functions, such as the blood pressure, are normally more or less fixed quantities. The student can learn instead that his blood pressure as well as other body functions vary and that part of this variability—large or small—is rhythmic and predictable.

These merits of authorhythmometry in education and health care compare favorably with the nuisance associated with it. Motivation and education can transform AR into a healthy challenge that may prompt one to pause at intervals and set aside everyday pressures. As to any risk, the problem of creating hypochondriacs has been considered in several instances and found to be negligible in the case of properly chosen and informed subjects.

Some Surface Autorhythmometry Studies

Shown in Fig. 1 is an extended autorhythmometry study conducted in 1963. It includes the dislocations caused by two intercontinental plane flights as well as the desynchronization during a two-week span of isolation. Several different physiologic variables were monitored.

During the first section of the total observation span, the subject measured his oral temperature and collected samples of his urine at 4-hr intervals from August 3, 1963 to December 4, 1963 (total of 890 samples). This section includes two transmeridian flights, one west–east from Minnesota to Central Europe and, after a 21-day stay in Central Europe, another one east–west back to Minnesota. From a psychologic viewpoint, one can hardly assign a direction such as "away-from-home" or "back-to-home" to a flight in either direction, since the subject had homes both in the USA and in Austria. He had married in Minnesota in 1959 and had thus established a new home in the USA where he had immigrated in January 1958. However, after the flight, in September 1963, he visited friends of long standing in West Germany and his parental home in Innsbruck, Austria, where he lived in his old room, left unchanged in an apartment shared with his parents. The European socio-ecologic niche had hardly changed since his departure a few years earlier.

The first west–east flight by jet from Minnesota to Hamburg, West Germany, departed from the Minneapolis–St. Paul airport on September 7, 1963, at 1345 CDT; after a stopover in New York, it arrived in Hamburg on September 8, 1963, at 0930 Central European Time (CET), following an intercontinental flight time of 6 hours. The time difference experienced by the subject during this flight was an advance (+) of 6 hours (CDT to CET). Travel within Central Europe during the following 21 days was not accompanied by any change in local time. The total amount of sleep and the time of retiring and rising in relationship to local time was, on the average, comparable to the schedule in Minnesota. The return flight departed from Munich, West Germany on September 29, 1963, at 1215 CET, and arrived in Minneapolis–St. Paul at 2200 CST. After the east–west flight the subject experienced a time change between CET and CST in the form of a 7-hour delay (–).

Figure 1 reveals that after the *abrupt* shift in timing of the socio-ecologic synchronizers by rapid transposition of the subject over six or seven time zones, the circadian acrophases adjust only *gradually* to this new synchronizer schedule, through a number of transient cycles. The speed and the extent of the adjustment seem to vary to some extent from function to function. The acrophases of oral temperature and of the urinary excretion of 17-hydroxycorticoids, 17-ketosteroids, and potassium reach the expected target phase during the 21-day span in Central Europe. The circadian acrophase of the sodium excretion rhythm, however, undergoes only a slight change in the expected direction. An anticipated advance of 90° after transposition over 6 time zones is not reached within 21 days, acrophase adjustment presumably requiring a longer time span. Study of this serial acrophase section further suggests a slower acrophase adjustment of certain functions (i.e., oral temperature and potassium excretion) after the west–east gain of 6 hours than after the east–west loss of 7 hours.

During a second section of the total observation span, from December 4, 1963, to February 2, 1964, the subject collected an additional 670 samples at unequal intervals, more frequently during the waking hours and with a longer sampling interval

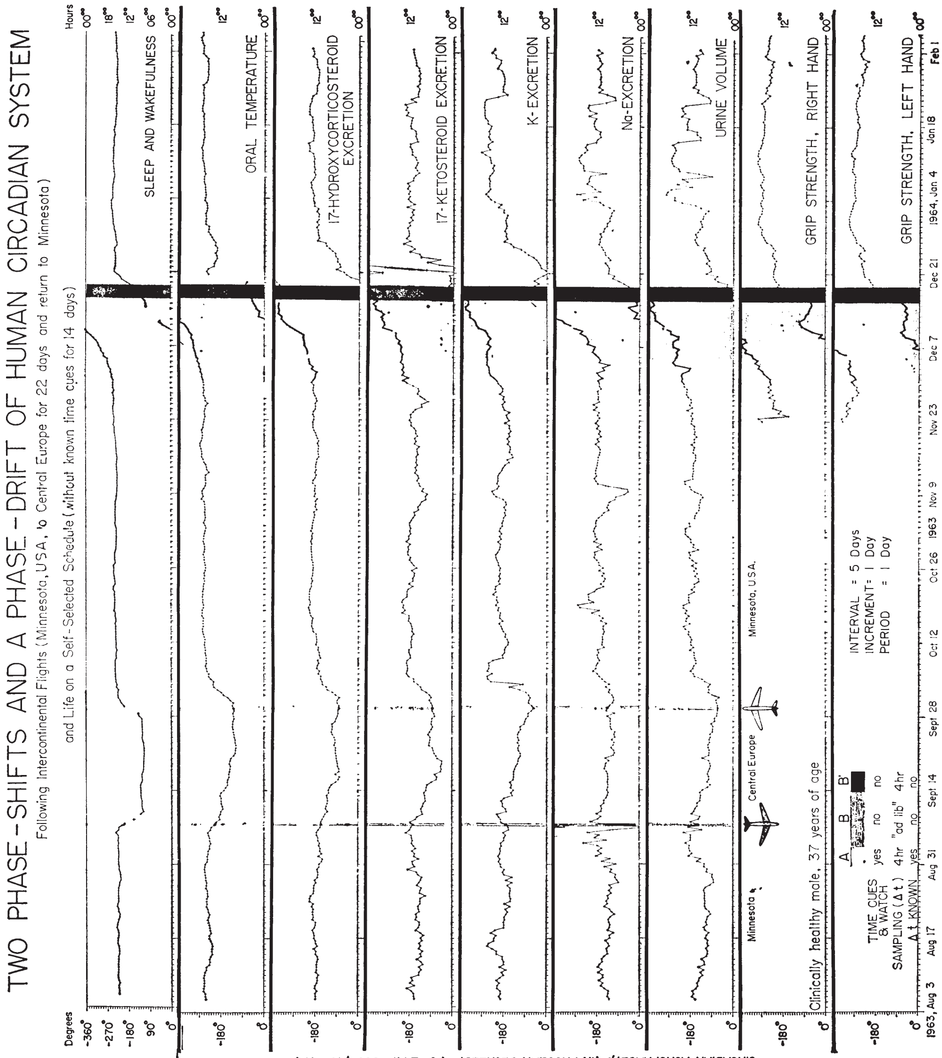


Figure 1. Serial acrophase section obtained by the least squares fit of a 24-hour cosine curve to time series on eight body variables, six of them studied over a total span of 184 days—August 3, 1963 to February 2, 1964—including (I) two intercontinental flights and (II) a 14-day time span in isolation without outside time cues. Acrophases shown in degrees as well as in Central Standard Time (CST) for entire observation span. The subject studied was a clinically healthy 37-year-old male physician-pathologist (Haus, 1970).

during uninterrupted sleep. This sampling schedule was instituted to avoid external time cues during a span from December 4 to December 18, 1963, when he lived without time cues in solo isolation. Apart from the time of travel and the time span in isolation without external time cues, the subject lived on a routine of predominantly diurnal wakefulness from about 0645 to about 2315 and nocturnal sleep.

From December 1 to December 18, 1963, the subject lived in the basement of the Cambridge State School and Hospital, Cambridge, Minnesota. The sole window of his specially prepared three-room apartment was sealed off completely from light. Noises which could have provided time cues were minimized in that part of the building. He entered the apartment on November 30, 1963. On December 4, 1963, the subject's watch was removed, and he spent the next 14 days without known outside time cues on a self-selected schedule. During this time, contact with the outside world was maintained by telephone communications with the Research Ward of the Cambridge State Hospital.

Communciation from the subject to the research ward consisted of code numbers for each of a number of activities, e.g., temperature measurement, urine collection, or times of awakening and retiring. Each message was coded by a random number. In the research ward the exact time of the telephone call and the number were recorded. Communication from the Research Ward to the subject consisted exclusively of whistle signals to avoid time cues by recognition of the voices of nurses and aids on the different shifts. The subject tried to estimate a 90-min sampling interval; a telephone call from the Research Ward was made whenever the sampling interval during waking hours markedly exceeded 3 hours. No such call was made after a "light off" signal from the subject. Communications with the isolation suite in this study closely resemble in design those used for numerous cave studies in other locations, but apartment life was more "conventional" in terms of usual kitchen appliances, bathroom facilities, and central heating. The subject cooked his meals, consisting of conventional foods; he refrained from the use of any of the famed local beers or other alcoholic beverages, and he did not eat bananas or items known to influence 5-hydroxyindoleacetic acid excretion.

The acrophase estimates obtained before, during, and after the 14-day isolation span without outside time cues are shown in Fig. 1. The isolation span from December 4 to 18 is lightly shaded. The acrophases of all functions studied during isolation form an oblique line, indicating a consistent difference between the rhythm's period and the period fitted (24 hours). As time proceeds the acrophases move upward; they occur later, a finding indicating that all of the rhythms studied had a period longer than that of the 24-hr cosine curve fitted to the data.

Much longer observation series are needed before one can rigorously interpret the long-term behavior of the phase–angle differences among the drifting oblique lines for consecutive acrophases; only to the extent that these appear to be similar for the several variables studied can one suggest the maintenance of internal synchronization during the 14-day span of external desynchronization of the subject's circadian system from the 24-hr routine. What is certain is that the longer-than-24-hr periods of the subject's circadian system during isolation led to a difference between the subject's "physiologic days" and the calendar day. Every day, with a single exception on Day 4, he retired a few hours later than on the previous calendar day. His sleeping pattern appeared "inverted" around the seventh day without outside time cues. At the end of the isolation span, the fifteenth day without outside time cues, the subject had experienced only 13 physiologic days. The subject was not aware of the lengthening of the "physiologic day" during isolation, and he felt no untoward physical or psychological effects.

After cessation of the subject's isolation from known outside time cues, immediate resynchronization with the environmental synchronizer schedule occurred only in the sleep–wakefulness pattern. All other body functions resynchronized only with a delay of several days, the duration of which seemed to vary from one variable to another.

The transmeridian flight experiences of the subject were repeated in 1967 with a second three-week trip from Minnesota to Central Europe. The oral temperature phase shifts observed in the same subject in the course of both trips are given in Fig. 2.

Four years apart, after shifts in phase of +90° and −105° in 1963 and of +105° and −105° in 1967, there is a remarkable similarity in the acrophase adjustment examined by the same chronobiologic technique of serial sectioning. In both instances synchronizer advance (after a west–east flight), as compared to a synchronizer delay (after east–west flight), leads to a slower acrophase adjustment. The observation of a faster delay than advance of certain circadian rhythms after abrupt phase-shifts of routine is in keeping with the results obtained on six men flying from Minnesota to Tokyo, Japan (a 9-hr synchronizer-shift) and returning to Minnesota after a 14 day span in Tokyo, and also with results of experiments on rats. However, in birds (Aschoff and Wever, 1963), the silk tree (Koukkari *et al.*, in press), and even in several men studied in a bunker (Aschoff, 1969; Kriebl, in Press), the advance of rhythms is faster than the delay. What seems to be consistent in broad comparative physiologic terms is a polarity (of one kind or another—faster advance *or* faster delay) in the response of circadian systems to a synchronizer shift in different directions as well as a "latency". In other words, if a rhythm is amenable to frequency synchronization with an environmental cycle (a condition that can be checked out by a stable acrophase), the ϕ of the rhythm will respond to an *abrupt* acrophase shift in the synchronizer by a *gradual* acrophase adjustment, the rate of which depends on whether this synchronizer was advanced or delayed.

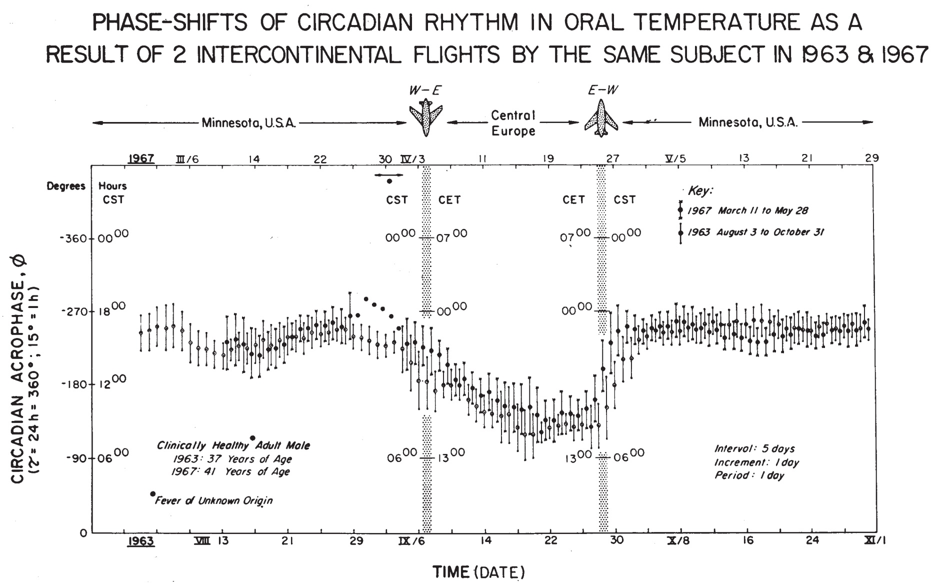


Figure 2. Circadian acrophase-shifts of oral temperature rhythm and their 95% confidence intervals before and after two transmeridian flights, in 1963 and again in 1967 (Haus, 1970).

Why Autorhythmometry During Prolonged Isolation Underground?

Before embarking on a study of autorhythmometry during a prolonged, isolated stay underground, it was necessary to consider the scientific benefits likely to be realized and to weigh this against the dangers involved, the ethical questions, and the expense which would be incurred. Only then could we feel that it was scientifically and ethically justifiable to take the calculated risk accompanying experiments involving human isolation underground. One may inquire into this problem with respect to isolation for several weeks as a pair or a group and, in particular, with respect to complete isolation (alone without time cues) for two months in the case of Michel Siffre, three months for Josy Laures, four months for Tony Senni, and for yet longer time spans (see Table 2). The following points came to mind concerning the usefulness of analyzing (for rhythms) data on several physiological functions collected during a prolonged stay underground of young healthy adults.

Isolation experiments allows us to investigate whether circadian and other rhythms persist or disappear in the absence of known synchronizers. If they persist, is there any dampening of amplitude? Do the rhythms' periods differ from those of known environmental cycles (external desynchronization)? Do the time relations of the organism's rhythms themselves change in the isolated individual? If so, are there merely differences in internal acrophases of internally frequency-synchronized rhythms? Alternatively, do we see differences in frequency among a given organism's many rhythms (internal desynchronization)?

The observations of Kleitman and Engelmann (1953) and those of Parmelee (1961) and Halberg (1963) on infants fed on "self-demand", as discussed by Hellbrügge *et al.* (1969), suggest the gradual rather than abrupt development of the circadian system. They demonstrate that, as it gains in prominence, the circadian system, by comparison to ultradian rhythms, can free-run prior to its synchronization with social schedules. However, such studies have usually been limited to sleep–wakefulness; internal time relations hence cannot be examined.

Even when multivariable studies are done on infants and children, experiences with the immature organism may not be comparable to what happens when synchronizers are removed insofar as possible from the mature, previously synchronized individual who has already developed a full circadian system. Desynchronization in the adult may be attained under conditions that render the subject nonreactive to the action of habitual synchronizers. Regressive electric shock (Fleeson *et al.*, 1957) is a case in point. Participation in such work may be made dependent upon several critical considerations. First and foremost is "informed consent", more unambiguously obtained from a speleologist or an astronaut than from a patient (submitting to psychiatric care) "ready" to receive electric shocks and to become disoriented in space and time as well as incontinent of bladder and bowel. In lieu of this approach, it is logical to advocate studies under controlled conditions in special environments with the exclusion of any and all time cues and with the application of objective methods of analysis, as was the case for the study in Fig. 1. Such work in special environments is the more warranted when, as in this particular study, AR is carried out for several months before and after isolation and when the manipulation of the circadian system by phase-shift of routine also is carried out on the same subject—as Fig. 1 demonstrates.

However, even the most interested subject (having plenty to read and music to hear), enjoying his isolation in a special room, may often be much less active than in usual life; briefly, he lives under conditions differing from his preferred usual activities. The speleologist, in turn, when isolated in a cave, as opposed to the scientist investigator who is not a speleologist, has the added advantage that in caves he can pursue his primary hobby unrestrained. It is from this viewpoint that the motivated and autorhythmometrically trained speleologist has provided superior information; his data are invaluable in terms of an isolation compatible with the pursuit of a hobby and over spans exceeding those covered by autorhythmometric studies in special surface settings such as those in Fig. 1. These considerations set the cave studies apart from other endeavors.

One may ask also whether in terms of environmental controls an isolated milieu such as a cave does not compare unfavorably with a specially outfitted laboratory. One could argue for a properly regulated isolator with the advantages of safety and relative constancy in the milieu. Caves such as those of the Scarasson and the Audibergue present sufficient guarantees as to the constancy in temperature and humidity, but, in fact, the decision in favor of caves comes from the subjects themselves, not the experimenters. It is relatively easy to find subjects ready to remain voluntarily in a natural cave underground for some months, whereas these same subjects would refuse a stay of the same duration in a comfortable isolator. The risk, the possibility of accomplishing a kind of exploit, quite apart from the publicity by the press, television, and movies, have an appeal which is not negligible. Moreover, and speleologists will certainly understand this sentiment, in a cave our subjects comport themselves as free individuals. In an isolator they may be only voluntary and anonymous prisoners. Two speleologists have considered their stays of one month in the hospital after isolation as an ordeal much more painful and tiresome than their three or four months underground.

There remains, also, the fact that the studies here presented are discussed in so-called microscopic terms, i.e., in the light of computer-prepared inferential statistical analyses rather than solely as gross impressions from the inspection of chronograms—that as such may not be amenable to an objective quantification of rhythm parameters. Some difficulties are shown in Figure 3 and discussed elsewhere (Halberg, 1969). The inspection of records is here deemed essential but not sufficient to arrive at all of the numerical indices desired for an objective description of the characteristics of rhythmic change.

A macroscopic inspection of the time plots in the top half of Fig. 3 contributes little: long-period changes of some regularity — presumably corresponding to the menstrual cycle—are apparent for rectal temperature in particular, and changes with shorter periods also are suggested by the record; yet to attempt to ascribe a precise period to a circadian rhythm or to discuss the phase relations of circadian components in the two time series seems unjustified on the basis of inspection alone.

By contrast, the display of acrophase in the bottom row—part of the microscopic approach—indicates first that the rhythms of both functions changed their period during isolation, only to be resynchronized with a 24-hr cyclic routine thereafter; second, that the rectal temperature acrophase lagged behind that for 17-hydroxycorticosteroid excretion during isolation, as well as following resynchronization; and third, that resynchronization of body temperature occurred considerably faster than that of 17-hydroxycorticosteroid excretion. The latter finding may be related at least in part to the circumstance that on the day of emergence from the cave the ϕ of rectal temperature was nearer its usual temporal placement in relation to the synchronizer than was the ϕ of 17-OHCS.

The pergressive amplitude diagram—third row from top—shows that the amplitude, notably that of the rhythm in 17-OHCS excretion during isolation, showed no indication of damping. This might be expected if rhythms are merely conditioned reflexes. If there was a difference between the amplitude at the end of isolation and that upon resychronization, this measure of the extent of circadian periodic change in 17-OHCS excretion indicated a more marked rhythm at the end of isolation than following resynchronization afterwards.

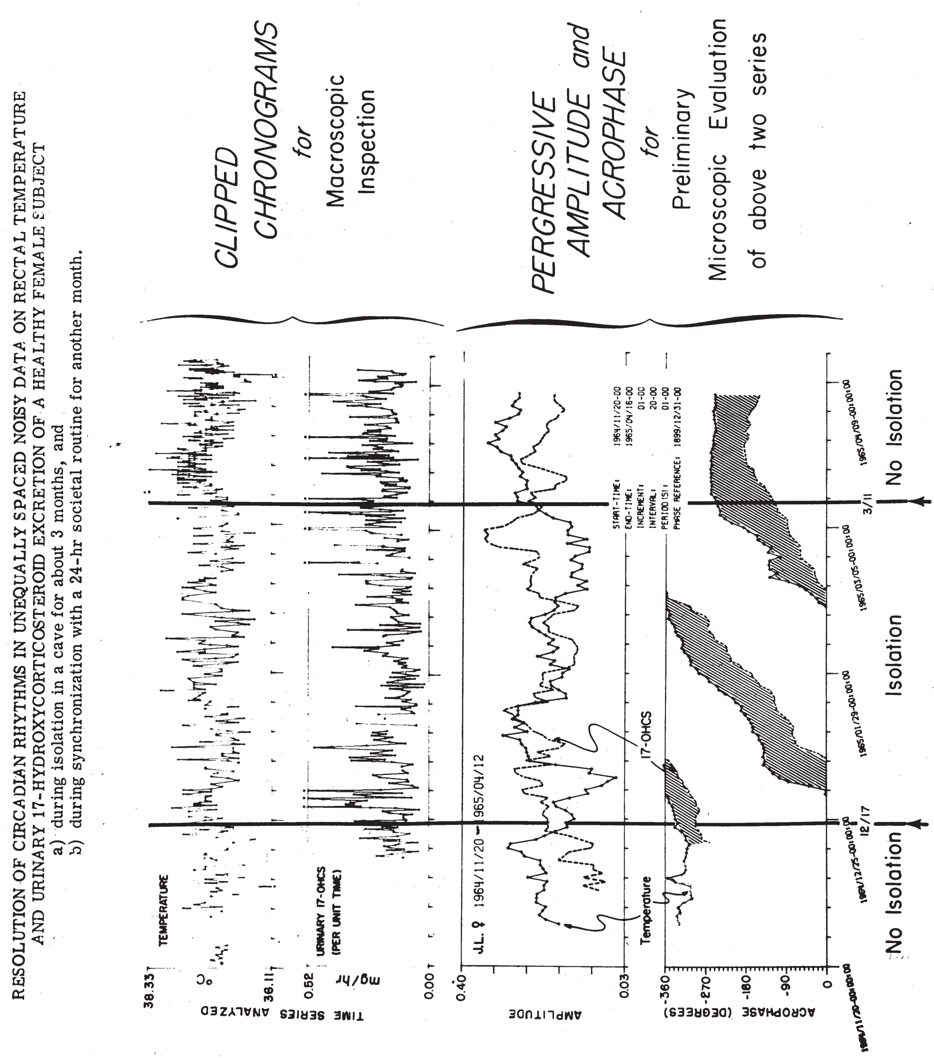


Figure 3. Acrophase relations of circadian rhythms in the urinary excretion of 17-hydroxycorticosteroids and in rectal temperature of a woman during isolation in a cave and following resynchronization with a 24-hr cyclic societal routine. A clipped chronogram of the time series is shown on top. (For clipping, values above or below the mean +3 standard deviations were repeatedly equated to the nearer of these limits until the result of this iterative procedure was no longer associated with a change in mean and standard deviation to the nearest four decimal places.) (Halberg, 1968.)

Illustrative Solo Isolation Studies

Subjects

Lines 5 and 6 in Table 2 describe adult subjects who volunteered to stay isolated underground in separate caves of the mountain massif of the Audibergue (southern part of the French Alps)—Ms. Josy Laures (JL) for three months and Mr. Tony Senni (TS) for four months.

JL, a midwife by profession, at the time of the study was unmarried, 25 years old, and weighed 117 pounds. TS, a master (handicraft) furniture maker (antique style), was married, the father of a family, 35 years old, and weighed 143 pounds at the time of study. Immediately before and after their isolation underground, the two subjects submitted to routine clinical (*inter alia*, cardio-vascular, pulmonary, renal, endocrine, nervous system and ophthalmic) examinations. No impairment of good health before their stay underground nor thereafter was detected.

The Subterranean Study Sites

Situated at 4429 ft above sea level, the two caves chosen are isolated from one another and are of relatively difficult access. The locations of the camps were at −266 and −230 ft from the surface; they received neither natural light nor noise from outside. Measurements taken before, during, and after the isolation studies showed that the levels of relative humidity (nearly 100%) and of temperature (42.8°F ±3.6°) varied only slightly.

Each of the installations consisted of a tent sheltering a bed, some tables and chairs, some materials for heating, cooking and lighting (powered by butane); diverse measuring instruments; an autonomous telephone line; some books, tools, etc.; and, near the tent, reserves of food, water, etc.

Each subject selected for himself a span of time during which to rest, sleep, be active, eat, etc. For nourishment, the subject could draw freely from his reserves—food preserved in cans or salt, plus vegetables and fresh fruits. Each subject lighted his heater and lamp at each awakening and extinguished them when retiring to sleep. The temperature of the interior of the tent during the waking spans would rise to 69.8°F; when the heat was extinguished the temperature dropped to around 42.8°F. The light from the gas lamps was on the order of 50 lux at 1 meter from the source. When moving around the cave outside the tent, each subject carried an electric battery lantern. This light was quite feeble. Each subject had clothes and boots chosen for protection from the cold and humidity.

The milieu was similar to that surrounding Michel Siffre during his stay of two months in a cave of the Scarasson. JL and TS benefitted greatly from Siffre's previous self-study, notably in matters pertaining to safety, equipment, and the management of subterranean camps.

Completion of Observations During Isolation

JL remained underground from December 15, 1964, to March 13, 1965 (88 days), without information concerning the local clock hour and date for 85 days (from December 17, 1964 to March 11, 1965). TS remained in his cave 125 days, from December 1, 1964 to April 5, 1965, without information concerning the local clock hour and date for 121 days (from December 2, 1964 to April 2, 1965). Multiple precautions were taken to deprive the subjects of all temporal clues. By means of an autonomous telephone circuit, each subject could call the surface crew at any time, but he could not receive thereby any indication of local clock hour, day, or month. One member of the surface crew was always awake.

The following data were registered on the surface according to the local hour: (1) the times of going to bed, awakening, and eating; (2) the times of urine collection (the output from each micturition, identified by a number, was saved in its entirety in a polyethylene flask containing 1 ml of a solution of merseptyl); (3) the number of radial pulsations per minute (the subject took his pulse between two phonetic "beeps" coming from the surface, with a time lapse between beeps varying from 1 to more than

1 minute); (4) the number of respiratory movements estimated in a similar way; (5) the estimation of a short interval of time, measuring on the surface with a chronometer the number of seconds the subject took to count from 1 to 120 with the goal of evaluating a duration of 2 minutes—a measure of "tempo" as well; and (6) the rectal temperature. Such data were obtained from each subject three to six times between the beginning and end of each waking span. Other data, relatively limited in number, concerned body weight, grip strength, the peak expiratory flow rate, and for JL, the beginning and end of menstruation.

The subjects could read, write, listen to recorded music, prepare meals, or engage in manual or physical activity, except for time spans occupied by sleep, rest, and different tests; also they had to carry their urine flasks to a "blind screen." The surface crew entered the caves irregularly, during the sleep of the subjects, to collect the flasks. The specimen of urine was evaluated on the surface; identified samples were frozen and transported for processing to the laboratory in Paris. Potassium and 17-hydroxycorticosteroid excretion were determined.

The alternating time spans of light-heat-activity and darkness-cold-sleep were self-selected; hence these schedules were independent of the local time. These experimental conditions (absence of known synchronizers) allow for the study on various functions of each subject of (1) external desynchronization, i. e., a modification of the period of the rhythm in each function with relation to the local time evaluated in cycles of 24 hours; (2) the eventual extent of persistence (or disappearance) of an internal circadian synchronization; and (3) other changes, e. g., relating to the internal timing of frequency–synchronized persisting rhythms.

Study of Resynchronization

After their stay in the caves, JL and TS were taken to Paris—in helicopter and airplane—to be hospitalized for a 1-month follow-up. They were permitted moderate diurnal motor activity, being confined to bed only for sleeping at night. Collection of urine and other measurements were continued. However, during this month of observation, the subjects were exposed anew to the influence of the synchronizer—the social routine with the alternation of day and night, meals at regular hours, variations in noise from hospital and urban activity, etc. Under these conditions, external circadian resynchronization of the physiologic functions studied was perceived.

Conclusions

Results of routine clinical and biological examinations indicate that the stay underground was well tolerated by the subjects studied by us. Ophthalmologic examination revealed transient modifications of visual functions, namely in the speed of chromatic vision (green and blue) and in binocular vision (Siffre *et al.*, 1966).

Plots of the sleep-wakefulness cycle for both TS and JL, as well as for Michel Siffre (MS) during his earlier two-month isolation in a cave (Halberg *et al.*, 1965b), are shown in Fig. 4. Displayed there are both the subjective estimate of elapsed time and the true elapsed time. From the comparison of charts in the first row with those in the second, all 3 subjects show that the subjective elapsed time follows a slower course than objective (actual calendar) time. When MS left the cave in September, he actually thought it was merely August. When TS left the cave on April 2, 1965, he believed that the calendar date was about one month earlier. Even more interesting are the impressions of JL, since menstruation recurring within a short subjective time interval will indicate to a thoughtful person that more time may have elapsed than one's estimation shows. Indeed, JL readjusted her record of elapsed time twice, each time prompted by a "premature" menstruation. Figure 4 thus indicates, as a first point, that in solo isolation, it is usually later than one thinks. This observation corresponds to experience gained in the

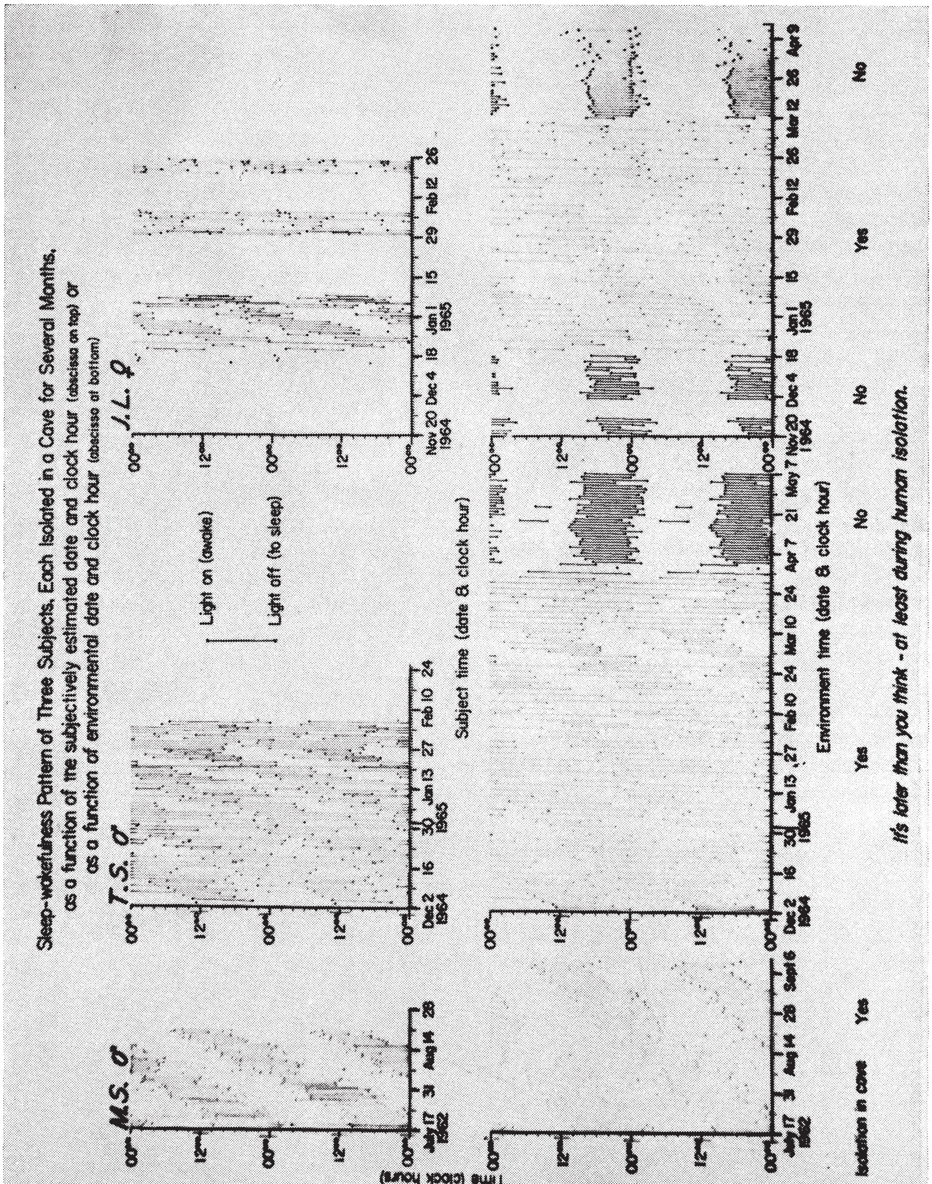


Figure 4. Subjective and objective sleep–wakefulness patterns of three subjects, each isolated in a cave for several months. In the top row, the abscissa represents the time recorded by the subject as his impression of time elapsed following entrance into the cave. The actual elapsed time is shown along the same time scale in the second row. For the last two subjects, portions of their sleep–wakefulness cycle while not in isolation but synchronized to social environmental diurnal activity on the surface are also shown.

isolation study in a basement apartment (Fig. 1).

A second point apparent from a macroscropic inspection of behavior day-charts is that rhythms differ in "regularity." Thus, unquestionably MS is rather "regular". One is tempted to take a ruler and draw an oblique line in an attempt to fit his successive times of awakening or retiring. However, even in this case, because of gross irregularities, on a few occasions one may have to guess at the slope of the line. The situation is more difficult toward the end of the isolation spans for both TS and JL (second row). To proceed according to some desiderata noted elsewhere (Halberg, 1969), it was essential to develop methods which remove subjectivity from the endeavor of assigning a period to a set of data, such as the sleep-wakefulness sequences shown in this figure. The results of such a method of spectral analysis are shown in Fig. 5. During isolation MS had a prominent circadian component at a trial period clearly different from precisely 24 hours. TS and JL had 24-h synchronized circadian rhythms on the surface but had both infradian and circadian rhythms in solo-isolation, the circadian rhythms being desynchronized from the 24-hour social day.

According to earlier suggestions (Halberg, 1960; Halberg *et al.*, 1960; Halberg and Reinberg, 1967), the degree of internal circadian synchronization of a subject studied in free-running conditions can be assessed by determining the periods of the circadian rhythms characterizing the physiologic functions studied and the acrophases of the rhythms in these same functions.

Thus, as observed in an earlier cave study (Halberg *et al.*, 1965b), the circadian rhythms of the pulse and sleep-wakefulness and the estimation of time by a healthy adult man (MS) during an isolation for 57 days became desynchronized from the 24-hr period, while a high degree of internal circadian synchronization in acrophase persisted between the rhythms of pulse and 2-minute estimation.

The effects on biological rhythms of the suppression of known synchronizers, such as hourly and daily constraints imposed by societal life, alternation of light and darkness, etc., have been studied objectively for several physiologic functions. Spectral analyses of data on these functions were carried out by the method of least-squares using computer programs developed at the University of Minnesota. The circadian components in the spectrum of rhythms characterizing sleep, radial pulse, rectal temperature, urinary excretion of 17-hydroxycorticosteroids, etc., were evaluated.

Spectral analyses of rectal temperatures for JL and TS during their isolation underground are presented in Figs. 6 and 7. For JL (Fig. 6) two peaks stand out above the general level of the spectrum. One of these is found at a trial period of 24.5 hours; it is the well-known circadian component. Further, the amplitude corresponding to a trial period of precisely 24 hours is negligible; this result attests to the occurrence of a circadian rhythm desynchronized from the 24-hr societal day. Note in addition a peak at a trial period of 621 hours, or 25.9 days, corresponding roughly to the intervals at which the subject's menstrual periods recurred during isolation in the cave. In isolation the deviation from 24 hours in the case of a circadian component and that from the circatrigintan period on the surface is shown by horizontal black lines on a shaded background.

One result of this analysis, not previously observed, is that while JL's circadian period lengthened (from 24 to 24.5 hr.) under desynchronization, her circatrigintan period decreased (from 28.3 days to 25.9 days). The functional relations between components with different frequencies, notably any interactions between circadian and reproductive organ cycles, await intensive study.

The temperature spectrum from TS (Fig. 7) shows again a circadian period, corresponding roughly to the length of a lunar day; in addition to a "lunidian" period, there is a second (infradian) component in the spectrum at twice the circadian component length, namely at 49.7 hours.

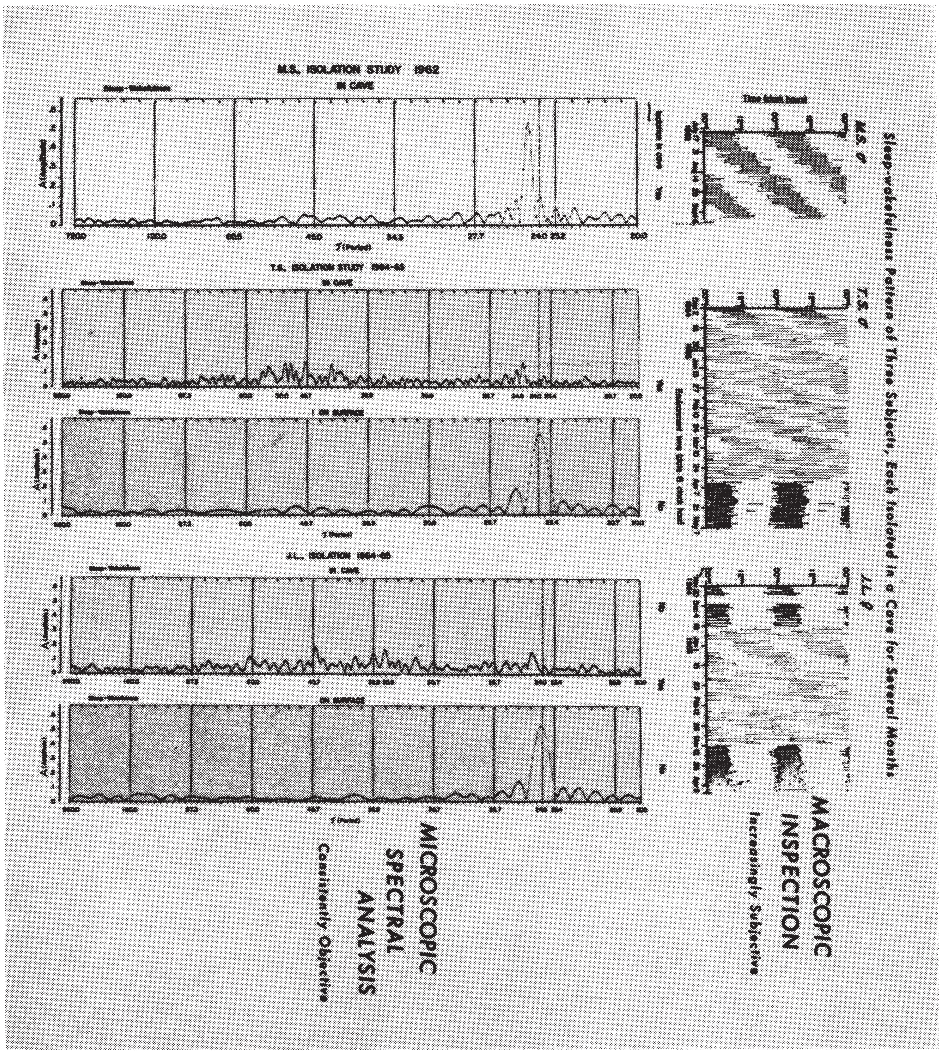


Figure 5. Least-squares spectra on sleep and wakefulness records of three subjects, each isolated in a cave for several months. The right hand column presents the macroscopic behavior day-charts (also shown in Fig. 4). The main column presents the microscopic spectral analysis of these data performed on the computer.

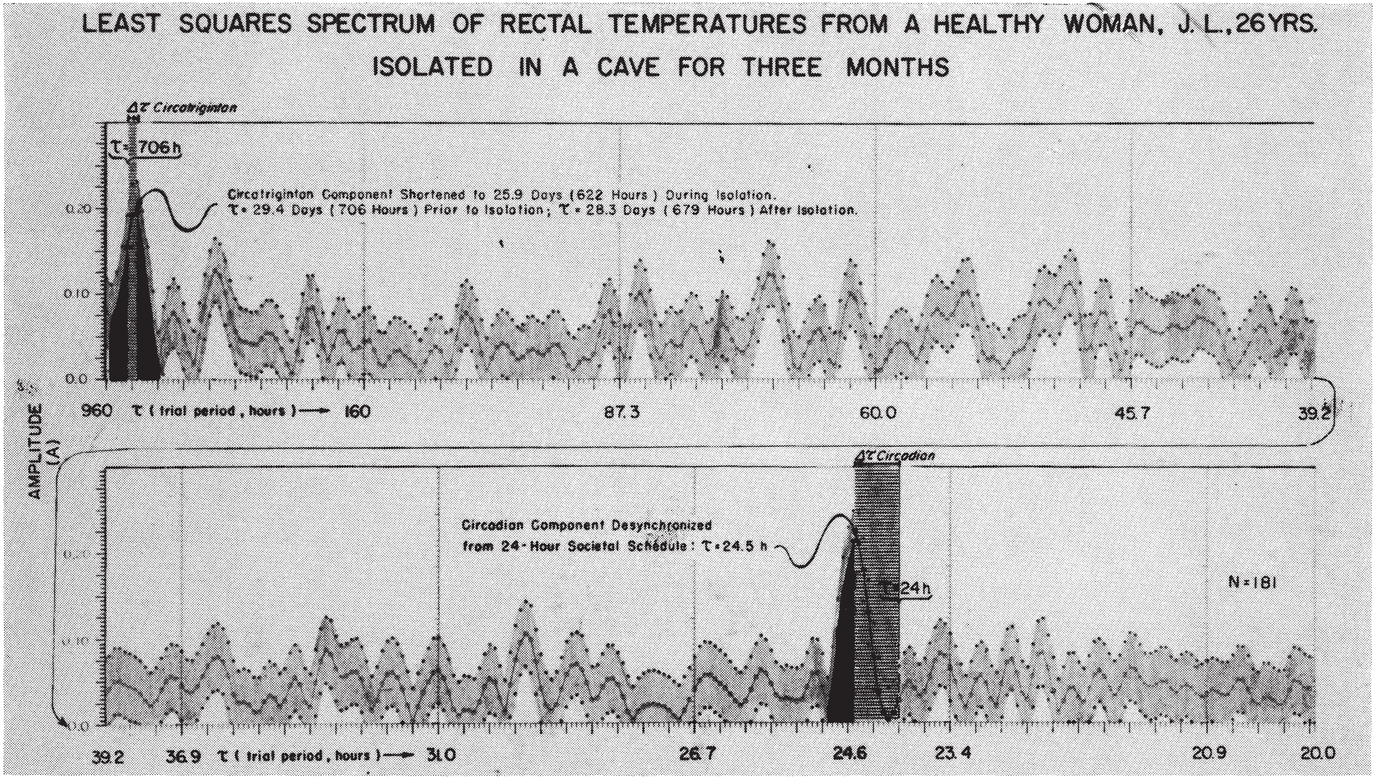


Figure 6. Frequency spectrum of rectal temperature recorded from Josy Laures while in solo isolation. Trial periods are plotted on the abscissa and corresponding amplitudes on the ordinate with standard errors above and below the amplitude given by the shading. The dark triangles are peaks corresponding to the circadian and circatrigintan components of the subject's temperature cycle. The vertical bars show the extent of shift in circadian and circatrigintan periods effected by the desynchronization of isolation (Halberg, 1968).

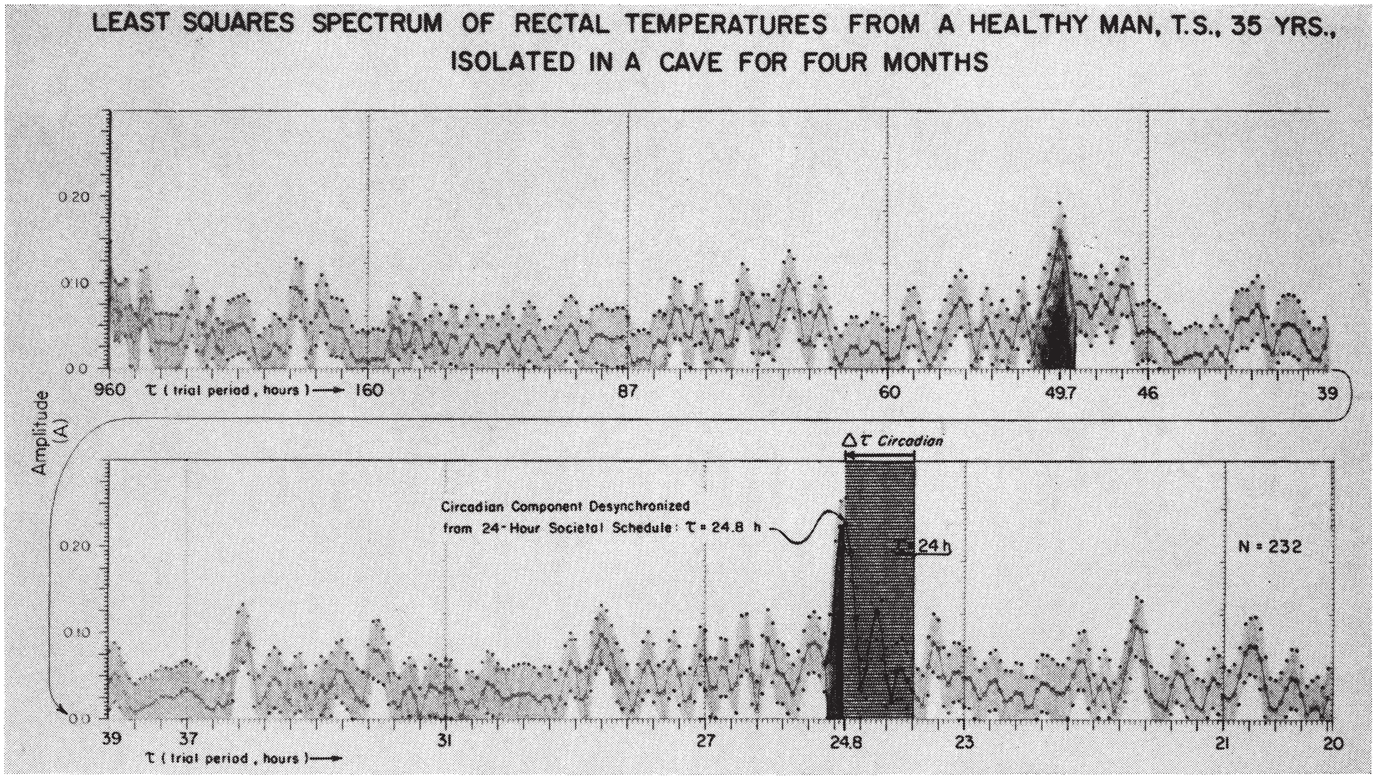


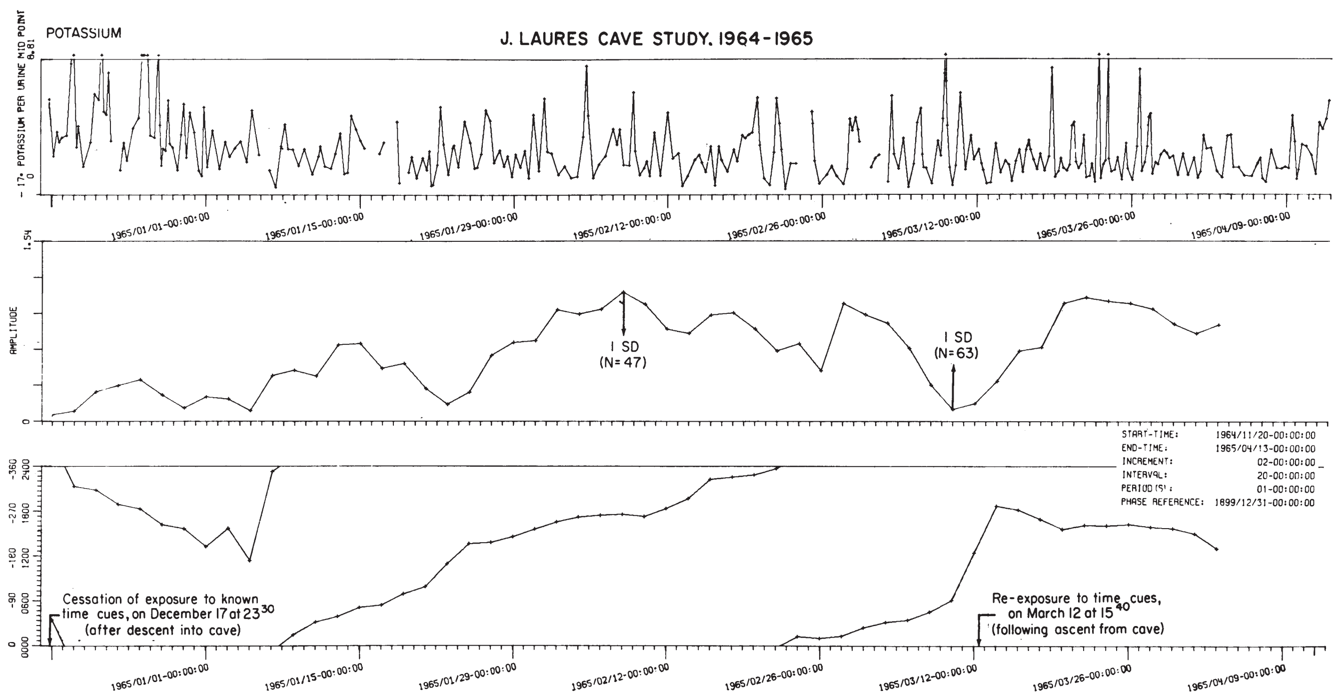
Figure 7. Frequency spectrum of rectal temperature recorded from Toni Senni while in solo isolation in a cave. Trial periods are plotted on the abscissa and corresponding amplitudes on the ordinate with standard errors above and below the amplitude given by the shading. The dark triangles are peaks corresponding to a circadian and a near-two-day component of the temperature cycle. The vertical bar shows the shift in the circadian period due to isolation.

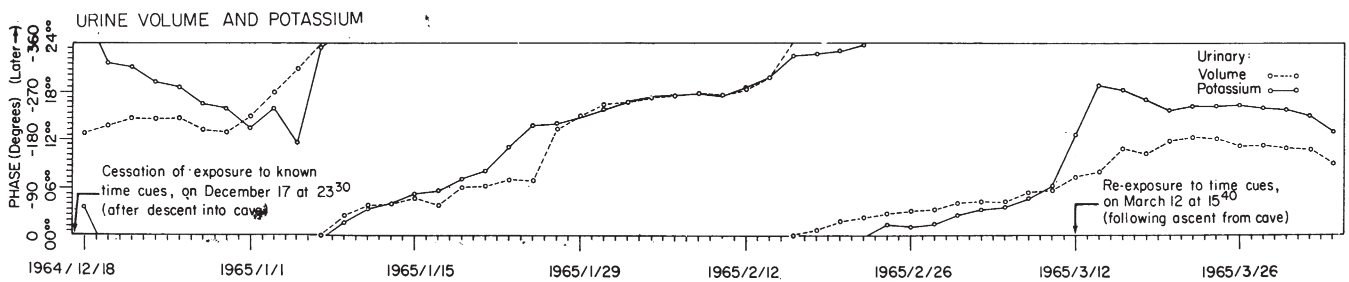
Macroscopic data on the amount of potassium in the urine of JL are shown in the top row of Fig. 8. The second and third rows give the amplitude and acrophase obtained from a spectral analysis of these data. When non-24-hr circadian rhythms characterize the data, as is the case in isolation, one expects to find that consecutive acrophases occur later and later, if the rhythm's period is longer than the 24-hr curve fitted, or that the consecutive acrophases occur earlier and earlier, if the rhythm's period is shorter than the period fitted. Initially the potassium acrophase (third row, Fig. 8) advances gradually; yet during this initial span, the ϕ is not reliable. The fit is poor, as can be seen from a low amplitude in the second row.

In any event, in the bottom row of Fig. 8 the acrophases for urinary volume and potassium seem to move in somewhat opposite directions for a week or longer before they eventually lock into phase. After this initial transient behavior during continuing isolation, they exhibit practically identical time relations—until the moment of emergence from the cave. After the arrow pointing to March 12, 1965, following ascent from the cave and during one month spent in Paris, the potassium acrophase clearly lags behind that of urine volume.

Having noted the difference in time relations of acrophases during isolation and societal synchronization (except for initial transient behavior), one may speculate whether a lag-in-phase of potassium behind volume, apparent during the resynchronization with the societal routine, may be due to specific or unspecific stimuli of everyday societal life. Under the latter conditions, potassium lags behind urine volume, a phase relation maintained for several weeks following the descent into the cave at the start of isolation on December 17, until new internal time relations come to the fore. The effect of lacking a societal setting may come to the fore but gradually, within a first month of isolation, and then persist until the very moment of ascent from the cave and return to societal life. The circumstance that the acrophases seem to anticipate the ascent from cave is due simply to the fact that consecutive 20-day intervals were analyzed; hence some of the intervals centered at a time-point before ascent from the cave include data collected on the surface. With respect to specific stimuli, one may ask to what extent a change in dietary intake and schedules may account for a difference in acrophase relations. Eating and drinking habits in the cave, as compared to the surface, may have unintentionally changed. Almost certainly subjects excrete a volume proportional to what they drink and by the same token, though perhaps to a lesser extent and less immediately, potassium output will depend on dietary intake. However, even the circadian water-excretion rhythm exhibits a partly endogenous component, as seen in a study on a 21-hr day carried out during the midnight sun in the Arctic and analyzed by modern computer methods (Simpson *et al.*, 1970). It also can be seen in the same study that a circadian rhythm in urinary potassium has a yet more strongly endogenous component, adjusting only in a minor way to a 21-hr "dietary (and activity) day". Thus, while changes in intake may well have been a factor, contributions from endogenous mechanisms of rhythms in both variables (to an extent differing between volume and potassium) can not be ruled out as underlying, at least in part, the phase relation here discussed.

Figure 8. Serial section of potassium excretion and urine volume during isolation underground and resynchronization by a 24-hr societal schedule. Plots of the original data on potassium during a three-month study of solo isolation of JL are shown in the top row. The circadian amplitude and acrophase for potassium are shown in the two middle rows. Plots for volume as well as potassium in urine are shown at the bottom. In the two bottom rows, the vertical scale corresponds to 360°, and in this case to 24 hours.


POTASSIUM
J. LAURES CAVE STUDY. 1964-1965
AMPLITUDE
1 SD
(N=47)
1 SD
(N=63)
START-TIME: 1964/11/20-00:00:00
END-TIME: 1965/04/13-00:00:00
INCREMENT: 02-00:00:00
INTERVAL: 20-00:00:00
PERIOD(S): 01-00:00:00
PHASE REFERENCE: 1899/12/31-00:00:00
Cessation of exposure to known time cues, on December 17 at 23^{30} (after descent into cave)
Re-exposure to time cues, on March 12 at 15^{40} (following ascent from cave)
1965/01/01-00:00:00
1965/01/15-00:00:00
1965/01/29-00:00:00
1965/02/12-00:00:00
1965/02/26-00:00:00
1965/03/12-00:00:00
1965/03/26-00:00:00
1965/04/09-00:00:00


URINE VOLUME AND POTASSIUM
PHASE (Degrees) (Later →)
Urinary:
Volume
Potassium
Cessation of exposure to known time cues, on December 17 at 23^{30} (after descent into cave)
Re-exposure to time cues, on March 12 at 15^{40} (following ascent from cave)
1964/12/18
1965/1/1
1965/1/15
1965/1/29
1965/2/12
1965/2/26
1965/3/12
1965/3/26

In viewing the acrophases additional questions come to mind and deserve more rigorous study. Is the rate of acrophase drift the same during the entire isolation span? This appears to be the case after January 6, 1965, for potassium and less so for urine volume. For the latter variable, one may consider the possibility that more rapid phase drifts alternate with slower drifts. The most prominent difference between the last two months in the cave and the first month after ascent from the cave is that in-phase synchronization (in solo isolation) was followed by synchronization with a difference in acrophase. Further research by speleologists is needed in order to find out whether the difference in acrophase noted on the surface is a measure of the loads impinging upon a person in a societal setting from social contacts. Along this line of thought, the first month in a cave is characterized by transients necessary for the extinction of such social effects, a process that in this case lasted for several weeks.

The analyses described above suggest that the circadian component for all the rhythms studied persists in the absence of known synchronizers and is desynchronized with statistical significance in relation to the local 24-hr clock time. Under the conditions of the study, the circadian period lengthened, and it differed with statistical significance from a precise 24-hr cycle. The rhythms were thus desynchronized in relation to local time (external circadian desynchronization). Certain phase relations among the rhythms themselves were maintained—e. g., the peak (acrophase) of the 17-hydroxycorticosteriod excretion precedes that of rectal temperature—indicating that this aspect of the time structure of the investigated organism persists in the absence of environmental synchronization. In subjects exposed to societal routines, the influence of synchronizers manifests itself in modifications primarily of the average period and also of the acrophase of certain circadian rhythms, notably when rhythms are evaluated in relation to the sleep-wakefulness rhythm. Such results can be compared with those of experiments yielding desynchronized periods in mice (Halberg, 1970).

The results as a whole provide further evidence to suggest that circadian rhythms depend, at least in part, upon factors that characterize the system rather than its environment and that environmental factors play primarily the role of synchronizers, modulators, or influencers (Halberg, 1969). The cyclicity of the social environment was certainly not required for the maintenance of circadian periodic body function in two human beings isolated in the absence of known time cues for durations of three and four months respectively. At the current state of knowledge, such results must not be generalized to other subjects, to other physiological variables, to other experimental conditions, or, of course, to other species; but the studies listed in Table 2 have provided only corroborative evidence thus far.

Individual Reproductive Isolation

An elimination of (or change in) sexual outlet and, in any event, abstinence from intercourse, constitutes a feature to be investigated on all subjects living alone in caves for long spans, whether they do so with or without time cues. There is a precedent that endogenous rhythms such as the menstrual cycle may alter their timing in solo human isolation (Reinberg *et al.*, 1966). Other-than-menstrual rhythms, notably yet not exclusively any of those related to male sex-gland functions, may also be affected.

The cave study on an individual's reproductive isolation may be aligned with that of reproductive *population*-isolation. Indeed, ecologic factors preventing gene flow from one population to another are regarded as critically underlying the branching of the phylogenetic tree—divergent evolution. Reproductive *individual*-isolation in a cave *may* be no less interesting and more readily amenable to scrutiny. More specifically, such solo isolation represents an important test-situation for assessing—by subtraction—the role probably played by a multitude of factors affecting man and his rhythms in a given contemporary socio-ecologic setting. Just as the role of endocrine glands can be tested by a remove–replace approach, so can the role of the socio–ecologic habitat be explored by first removing as far as possible any and all specifiable environmental factors and by thereafter replacing one factor at a time, for a study of any effect upon rhythm characteristics.

Other Isolation Studies

Experimental conditions of J. N. Mills' isolation studies (Mills, 1966 and 1967) are similar to those we have just summarized. For instance, in March 1966, D. Lafferty descended into Boulder Cave in Cheddar where he remained alone without time clues for 127 days. A telephone line continuously manned at the surface enabled him to transmit information about his times of going to sleep and waking. The isolation study on G. Workman differs from the others on one point: this subject had a watch and thus was able to know the clock hour. However, this time information was not related to any special duty or task—in other words, to social activities. Indeed, external desynchronization occurred in this subject as well.

By 1938, N. Kleitman (1965) had used Mammoth Cave in Kentucky as a milieu to study the effect of an artificial routine (light to dark ratio = 9:19) on circadian rhythms under naturally controlled conditions (i. e., temperature = 54°F ± 1°; humidity $\cong$ vapor saturation; complete darkness when artificial light was turned off). Oral temperature was recorded every 2 hours during waking and 4 hours after retiring by two healthy male adults from June 4 to July 6. Macroscopic examination of recorded time series led Kleitman to the conclusion that one of the subjects adjusted to the 28-hr schedule while the other one did not adjust and maintained his temperature rhythm on a period close to 24 hours.

The effect of an artificial routine (21-hr day) on several circadian urinary rhythms also has been studied by H. Simpson, M. Lobban, and F. Halberg (1970) in data obtained under the naturally "continuous" midsummer light in Spitsbergen. Microscopic analyses of these times series indicated that different circadian rhythms are controlled by different mechanisms. Use of a cave as well as of the arctic (or antarctic) winter

TABLE 2. Studies in caves on human circadian rhythms in various physiologic functions.

Study Kind	Year	Subjects (No.)	Routine or watch	Duration (days)	References
Pair or group	1938	2 men	28-hr.-day	32	1
	1965	7 women	None	14	2
	1962	M. Siffre	None	62	3, 4
	1963	G. Workman	Watch	105	5, 6
Single isolation	1964–5	T. Senni	None	125	3, 7– 9
	1964–5	J. Laures	None	88	3, 7–11
	1966	D. Lafferty	None	127	6, 12
	1966	J. Mairetet	None	153	13, 15
	1968	J. Chabert	None	120	16
	1968	P. Englender	None	120	16

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1. Kleitman, 1965
2. Apfelbaum *et al.*, 1969
3. Halberg and Reinberg, 1967
4. Halberg *et al.*, 1965b
5. Mills, 1964
6. Mills, 1967
7. Ghata *et al.*, 1969
8. Reinberg, 1968
9. Siffre *et al.*, 1966
10. Reinberg *et al.*, 1966
11. Reinberg, 1970
12. Mills, 1966b
13. Colin *et al.*, 1967
14. Fraisse *et al.*, 1968
15. Jouvet, 1968
16. Unpublished, see Luce, 1970

or summer, despite limitations considered by others (Corbet, 1969), is pertinent to explorations of the effects of manipulation and/or suppression of known synchronizers.

M. Apfelbaum *et al.*, (1969) isolated a group of 7 young, presumably healthy women for 14 days without time cues in Lacave Cave, France. The data on the sleep–wakefulness rhythm from this underground isolation of a small group of volunteers were analyzed microscopically; inter-individual external circadian synchronization on a frequency different from precisely 24 hours was revealed. Microscopic analyses of these time series during isolation show more specifically:

(1) a statistically significant desynchronization from exactly 24 hr;

(2) a similar prominent circadian period (τ = 24.7 hr) in all the subjects; and

(3) a statistically significant difference in acrophase between a subgroup of 3 women and another of 4 women, living in separate tents.

The results of this experiment can be taken as an additional line of evidence demonstrating that socio-ecological cycles are a primary synchronizer of circadian rhythms in human beings.

In the seven subjects isolated as a group, the prominent periods detected by the least squares spectrum cluster at 24.7 hr, and the inter-subgroup differences in acrophases allow the recognition of tent mates, yet all of the acrophases are rather close to one another. While the synchronization by social group factors is considered to be more critical, the chance of a lunar-period influence on the behavior of a circadian system desynchronized from the 24-hr "societal-solar" day must be kept in mind, notably for human beings living in caves at low levels of illumination, as in the case of the women here discussed.

The effect of unusual routines, explored in a study in the Mammoth Cave, Kentucky (Kleitman, 1965), has also attracted the attention of "circumpolar" investigators. During the winter, areas within the arctic circle share with caves the condition of darkness and thus impose on man a dependence on artificial lighting—light that may be manipulated at will. The arctic, as well as the cave, provides more freedom of movement than an apartment or bunker, and the availability of polar travelers as well as of speleologists to act as autorhythmometrically active subjects allows the study of individuals actively exploring regions of special interest to them.

Furthermore, the polar summer is characterized by relatively small variations in sunlight during the entire 24-hr span; a really dark "night" must be simulated in an enclosure, such as a tent or building. These photic characteristics give the polar regions an advantage. Moreover, work being done in arctic areas may yield ecologic and medical information relevant to the well-being of the indigenous Eskimos, Samoyeds, Aleuts, Lapps, and other peoples possibly exhibiting interesting genetic adaptations of biorhythms to the distinctively different changes in arctic photofractions (Simpson *et al.*, 1970).

Scientists with an affinity for polar areas, as well as natives of the arctic, also are among the potentially most fruitful contributors to chronobiology. By the same token, speleologists, who already have constituted pioneering contributors to rhythmometry, can be expected to continue to teach new lessons for a better understanding of life above ground as well as in aerospace.

Since this manuscript was first accepted for publication, additional isolation studies underground have been performed on healthy subjects in natural caves in France, and a new study is about to start in Texas. Several aspects of these new studies related to solitary isolation have been reported (Colin *et al.*, 1967; Fraisse *et al.*, 1965; Jouvet, 1968) but as yet they are limited to the examination and "mascroscopic" analyses of time plots of data, *inter alia,* on variations in sleep–wakefulness, time estimation, and body temperature.

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Proceedings of the Society

MEETING IN LOVELL, WYOMING, JUNE 1969

DATA PROCESSING SESSION

IMPURE MATHEMATICS

Lee H. Skinner

A digression on the relations between Polly Nomial and the smooth operator, Curly Pi. After removing her discontinuities, the operator integrates the absolutely convergent Polly Nomial and thereby generates an expansion.

DATA RETRIEVAL AND CAVE FILES

W. W. Varnedore, Jr.

The sheer mass of data in state cave survey files and the NSS cave files makes finding a specific piece of information a formidable task. A technique of encoding the data to compress it and of using automation to order it for specific indices is presented.

ASCDIF—A PROPOSED AMERICAN STANDARD CAVE DATA INPUT FORMAT

Robert G. Babb II

Motivation is presented for establishing an American standard format for key-punching Brunton survey data. One possible data acquisition system is proposed. The system consists of a survey form for recording the data and a variety of standard program cards for key-punching data from the form. If the system gains acceptance, the author offers to write standard input routines in ASA FORTRAN and Algol so that a minimum of re-programming of existing survey programs would be necessary to convert them to accept ASCDIF.

SPELEOMAP V AND VI, CAVE MAPPING PROGRAMS

Charles A. Plantz and Victor A. Schmidt

These two programs take raw survey data, compute the coordinates of the stations, and plot a skeleton map of the cave on a Calcomp plotter. A corrected version of the map, in which all closure errors are corrected by a least squares procedure, is also computed and plotted. Speleomap VI, which will hopefully be debugged by convention time, includes advanced plotting features and the ability to take survey sight data cards in any order.

ORDERED LOOP SYSTEMS AND ASSOCIATED ERROR MINIMIZATION OF BRUNTON CAVE SURVEY BY COMPUTER

James M. Hardy

This paper will discuss an algorithm for obtaining minimum loop systems and their associated line networks in undirected line topologies. It will cover the resulting error analysis found in actual Brunton cave surveys. A system for minimzing the resultant error by varying the base loops will also be presented.

KEYTAPE SYSTEMS AND THEIR POSSIBLE EFFECT ON THE PROPOSED CAVE FILE FORMATS

M. J. Stupak

This report is in no ways a recommendation for any proposed format or tape system. It is merely a report on the advancement of the state of the art and its possible effects on the present and proposed systems.

MEETING AT STATE COLLEGE, PENNSYLVANIA, AUGUST 1970 GEOLOGY SESSION

ORIGIN OF MAZE CAVES

Arthur N. Palmer
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A maze cave consists of a labyrinth of intersecting passages of relatively uniform character that have undergone simultaneous, rather than sequential, development. Such caves commonly exhibit one of the following patterns: a network pattern, in which enlargement has taken place rather uniformly along many intersecting joints, or an anastomosing pattern, in which tubular passages interconnect in a braided manner along a bedding plane or in a three-dimensional zone of spongework.

The origin of maze caves depends upon a mode of ground-water recharge that subdues the tendency for the largest passages to transmit ground water at the highest velocities and, therefore, to undergo the highest rate of solutional enlargement in a "self-accelerating" manner. Two distinct patterns of recharge commonly form maze caves: (1) recharge in the form of local infiltration above the zone of passage enlargement, rather than as ground water conducted laterally from adjacent source areas, and (2) concentrated recharge at a point source that undergoes extreme variation in discharge and local hydraulic head, as in the case of a sinking stream. In case (1), the enlargement rate of passages is a function mainly of the infiltration capacity above the cave, rather than of passage size. Cave development, mainly of network pattern, may take place under phreatic or vadose conditions and, in many cases, both. Caves of this type occur beneath thin, insoluble but permeable caprocks, beneath local topographic highs, or in the up-dip edges of cuestas. In case (2), the extreme variation in discharge prohibits any single passage from remaining adjusted to the flow, and floodwater routes are developed around low flow channels that are generally restricted in their enlargement rate by stratigraphic or depositional conditions. Cave development, mainly of anastomosing pattern, takes place under alternating flooded and dry conditions.

Maze development has no inherent relationships to structural conditions at the axes of folds nor to artesian ground-water flow.

MEASUREMENTS RELATING FLOW MARKINGS TO FLOW VELOCITIES

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Haifa, Isreal
Rane L. Curl
University of Michigan
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The experimental production of flow scallops on a soluble surface and a parallel study of the stability range of flow fluting have confirmed a previous estimate of a stability Reynolds Number of about 25,000. Scallops, if measured on the basis of a root-mean-square maximum reach, provide an estimate of the flow velocity producing them.

AN ATTEMPT TO CLASSIFY CAVE SEDIMENT ENVIRONMENT AND PROVENANCE TYPES

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Three karst basins are examined, and the movement of clastic fills is described in each. A classification of sediment environment and provenance types is proposed based upon:

1. The profile of the karst basin
2. the function of caves within each basin
3. the changes in profile and function of the system throughout the development of the caves.

SIMMONS-MINGO: A CAVE CARVED BY AN UNDERGROUND STREAM

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Simmons-Mingo Cave and the closely related My Cave have been explored and mapped. The development of Simmons-Mingo is explained. Various theories concerning phreatic and vadose flows are discarded as being inapplicable or overly elaborate. The cave is best described by the earliest ideas concerning the development of caves. A stream flowed underground from one level to another and, in doing so, carved out an immense (over three miles) cavern.

CERTAIN ASPECTS OF THE HYDRAULIC GEOMETRY OF KARST DRAINAGE SYSTEMS

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Karst drainage basins within the Cave-In-Rock area of southeastern Illinois were subjected to analysis of their surface hydraulic geometry involving the comparison of depression frequencies, depression catchment areas, depression catchment relief values, and depression orders, which are defined by the highest Horton order of all streams flowing into the depression. This represents an attempt to assess the hydraulic geometry of karst systems using a modified form of Horton analysis, and karst drainage systems were found to exhibit similar characteristics as surface stream systems. Implications of these morphometric relationships with respect to cavern morphology are then discussed.

HYDROGEOLOGY OF BURNSVILLE COVE, VIRGINIA

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The Sinking Creek Cave System in Burnsville Cove, Virginia, is an example of a cave system developed in a confined-flow carbonate aquifer in which there are geologic boundaries as well as hydraulic factors controlling the flow rates and cave morphology. It is developed in the Silurian Tonoloway and Keyser Limestone in the Ridge and Valley Province of the Appalachian Mountains. Cavern development in the aquifer is strongly joint controlled and follows the structure of the enclosing limestones and sandstones. The cave system consists of a series of network side caves developed in the flanks of the Burnsville Cove Syncline feeding down dip into the main trunk channel which is developed along the plunging Burnsville Cove Synclinal axis.

Five caves form the integrated drainage system of the Sinking Creek Cave System. They are Boundless, Butler, Breathing, Better Forgotten, and Lockridge Aqua Cave and Spring, which is the resurgence along the Bullpasture River. Lockridge Aqua Spring has an average flow of 210 liters/second, which is sufficient flow to account for all of the known cave streams in the system.

There is now evidence from fluorescein dye studies that two more large cave systems exist in the Burnsville Cove area. One drains the southeastern side of Chestnut Ridge and the other drains the area northeast of the Sinking Creek Cave System.

HYDROLOGY AND SPELEOGENESIS OF THE LOS SABINOS AREA OF THE SIERRA DE EL ABRA OF NORTH-CENTRAL MEXICO

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Previous works by Bonet (1953) and Enjalbert (1954) attempted to cover the karst of the Sierra de El Abra, but there remains an acute lack of specific data concerning the karst hydrology and speleology of the area.

In a classic guide to the caves of Sierra de El Abra, Russell and Raines (1957) have interpreted the speleogenesis of the area as occurring in two stages: extensive but isolated solution beneath the water table, followed by integration of these phreatic features by stream capture associated with continuing erosion.

Recent study associated with detailed mapping of the caves of the Los Sabinos area of the Sierra de El Abra indicates that the initial stage of cave formation occurred about a fluctuating water table, producing isolated chambers and conduits, depending on the solubility of the country-rock and the velocity of the water. These chambers and conduits were formed by a fluctuating water table at various hydrologic levels during periods of relative stability. Subsequent invasion of surface streams has integrated these isolated features into extensive hydrologic systems, presently both above and below the water table, that now control the drainage for a large portion of the Sierra de El Abra.

MORPHOLOGY AND GENESIS OF DEEP PITS IN THE AQUISMON AREA, S.L.P., MEXICO

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Seven large, deep pits have been mapped near Aquismon, S.L.P., in the Sierra Madre Oriental. These pits and numerous others are all found in the massive El Doctor Limestone. Entrances occur from 1500 to 2400 ft elevation on the flanks or crests of hills or ridges. No direct surface drainage enters the pits, and dolinas have not served as collecting basins for the shafts.

The pits closely resemble elliptic cones, some being nearly circular. The relative importance of major fractures controls the length-to-width ratio of the plan, and the amount of collapse varies the profiles. Few passages or phreatic voids are found in the jagged walls. Breakdown, guano, and sparse shrubbery cover the floors of the shafts so that no bedrock floor is exposed. Some of the pits have subsidence troughs, especially Sotano de las Golondrinas which has one 70 ft deep, and Sotano de Cepilla, where cemented breakdown extends vertically for about 100 ft along a portion of its perimeter. Also there are a few trenches formed by water inlets on the walls. Chemical deposits are not abundant; they generally take the form of wall flowstone or massive flowstone banks and columns.

Sotano de las Golondrinas, the largest pit explored, has an entrance 200 ft in diameter, and it widens out to a floor 440 ft by 1000 ft about 1100 ft below. Golondrinas has a void space of about 200,000,000 ft^3 and Hoya de las Guaguas, the second largest pit, has over 150,000,000 ft^3. Both pits are developed along major fractures which is probably the most important factor in generating their huge size.

The model proposed for the origin of the pits is: (1) development of a large, deep (below the surface), phreatic chamber; (2) enlargement by gradual stoping of ceiling rock, aided by percolation water in loosening joint blocks; and (3) solutional removal and subsidence of breakdown debris (this process is probably still occurring). Occasional higher caves may have also fed water down major fractures to the chamber. The depth of a pit depends on the elevation of the initial chamber, the amount of debris removed, and the amount of surface erosion. The well-developed surface karst which allows rapid infiltration of rainfall to great depth and the scarcity of shallow caves and phreatic voids lend support to the model.

FLUORESCENCE AND PHOSPHORESCENCE OF CAVE MINERALS

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A systematic examination has been made of the luminescence behavior of a large number of cave minerals under 254 nm UV excitation. As has long been reported, most specimens show a slow decay green-white phosphorescence. The phosphorescence occurs with the same color and decay time in all active specimens. Bright green, orange, yellow-green, and white have been observed. Many specimens show no fluorescence but are still phosphorescent. Aragonite exhibits a pastel lavender emission and is also phosphorescent with a color and decay similar to calcite. Some specimens of gypsum fluoresced and phosphoresced a blue-white. Vein calcites from the same limestone in which many of the caves were formed show neither fluorescence nor phosphorescence. The characteristic red emission typical of Mn^{++}-doped calcite was not observed.

LITHOLOGIC CONTROL OF CAVE DEVELOPMENT

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The object of this study was to determine the stratigraphic and lithologic controls on the distribution of caves within a heterogeneous sequence of carbonate rocks. The volume of all accessible caves with length greater than 100 ft was measured in the Nittany Valley area of Central Pennsylvania. The caves occur almost entirely within the limestones; cave development in the dolomites is extremely rare. Within the limestone sequence the bulk of the cave volume is concentrated in a few members. Chemical and petrographic analyses of the carbonate rocks were associated with cave volume by plotting distributions of average cave volume against lithology. The more cavernous carbonate rocks are those with relatively small amounts of dolomite, clay, and other impurities and with relatively large percentages of micrite (fine carbonate) and low percentages of sparite (coarse carbonate). There is no direct relationship of cave development with either percentage pyrite or percentage allochems (carbonate grains). Field observations show that shale layers retard solution of sandwiched limestone beds and that silty streaks enhance small-scale solution development; silty streaks are probably associated with major cave development as well. Several proposals are made concerning the mechanisms of lithologic control of solution development.

FACTORS CONTROLLING STRATABOUND SOLUTIONAL ACTIVITY IN THE GALENA FORMATION OF IOWA. RESULTS OF INITIAL QUANTITATIVE INVESTIGATIONS

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Results of field studies reported previously (*NSS Bulletin,* April 1969) confirmed that solutional activity in the Middle Ordovician Galena Formation in and near the Upper Mississippi Valley had been stratabound in character. Activity had been maximized at 0, 43, and 95 feet beneath the top of the Stewartville Massive member of the formation irrespective of local structure or relationships to relicit local and regional geomorphic surfaces. Two factors were cited as controls on the position of cave development, control of passage trend by the presence of well-developed joints and control of stratigraphic position by the presence of several sets of beds which were definitely more susceptible to solutional attack than were those of the remainder of the formation, as confirmed by laboratory examination of samples taken near caves in the vicinity of Dubuque, Iowa.

Determination and quantification of the lithologic factor(s) responsible for the differences in susceptibility were the objectives of the present research. The samples were subjected to quantitative examination using methods developed and/or adapted by Dr. John Lemish *et al.* at Iowa State University. Cores were subjected to wet chemical analyses determining acid insoluble residue, CO_2, SO_4^{--}, CaO, MgO, Na_2O, K_2O, Al_2O_3, Fe_2O_3, and H_2O concentrations. Duplicate cores were subjected to analysis with an air permeameter and a mercury injection porosimeter.

Because of the extremely low permeabilities (less than 0.4 millicarcy) found in all fresh samples, irrespective of affiliation with cap or containing bed groups, no significant water flow through rock pores occurred; this is supported by field observation, in that disseminated solutional effects are rare to absent. In addition, no geologically significant differences in chemical or mineralogical composition were found between the two groups of beds.

The major difference between the groups is their porosity. The containing group has an abundance of large size pores (0.6 to 20.0 microns radius) with respect to the cap group (0.05 to 0.60 microns radius). Most of the pore volume occurs in the 4 to 15 micron range in the containing beds and in the 0.06 to 0.20 micron range in the cap group. Assuming pore sphericity, the effective surface area exposed to solutional attack within a unit area of joint surface is about 2000 to 5000 times as great adjacent to a containing bed as it is adjacent to a cap bed, depending on pore density. This factor allowed solution to proceed at a faster geologic rate in the containing group.

CALCITE SATURATION OF AN EASTERN KENTCKY KARST STREAM

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Calcite saturation, expressed as the log of the ion activity product-solubility product ratio (SAT), was determined for waters of Cave Hollow, a small karst valley in Lee County, Kentucky. Field and laboratory chemical analyses plus Debye-Hückel activity coefficients and ion pairs corrections were used.

Tributaries on the Pennsylvania clastics were always grossly undersaturated with respect to calcite, $-5.0 < SAT < -3.3$ ($SAT = 0$ at saturation; negative values indicate undersaturation).

About 200 m (650 ft.) after sinking into Mississippian limestone, the cave waters increased SAT to -2.7 to -1.6 in the springtime and to -0.3 to $+0.1$ in the late summer and autumn.

All water emerged from a spring about 1 km (3300 ft.) from the sinks. Values for SAT were similar to those at 200 m with the same seasonal variation but were generally slightly less saturated ($-2.1 < SAT < -0.1$).

Higher saturation was observed in late summer and autumn than in springtime. This appears to correlate with discharge. Calcite saturation and total calcium were considerably less for high flows than for low, however, the amount of calcium in solution did not decrease as fast as discharge increased. More limestone was dissolved during periods of high flow (about 105 cc/day) than during low flow (about 3x103 cc/day).

Water initially grossly undersaturated with respect to calcite became moderately undersaturated in 200 m of travel through limestone and thereafter changed in saturation very little. Water after 1 km of flow was still quite able to disolve calcite.

CAVE PHOTO/CINEMATOGRAPHY SESSION

Film—"IN THE CELLARS OF THE WORLD"

Introduction by George F. Jackson
1927, 16mm, silent (titles), b&w, 30 min
Producer & Director: Russell Trall Neville

This rare film, better known simply as "The Neville Films", ranks as one of the earliest successful efforts to record natural cave scenes with a motion picture camera. It will be introduced by George Jackson who personally knew the photographer, Neville, and was present when some of the footage was shot. Some notes on the historic significance of the film and on the equipment and techniques used in its production will be provided.

PHOTOGRAPHIC LIGHTING AND COMPOSITIONAL CONTROL IN CAVES

Victor A. Schmidt

The use of various sources of instantaneous light (i. e., flash, strobe, etc.), their placement, and proper application with a view toward dramatic effect and good composition in situations ranging from the close-up to the wide shot will be demonstrated.

CARBIDE LIGHT CAVE PHOTOGRAPHY

Daniel Gealt

The reasons for shooting photographs by carbide light and the unusual results that can be thus obtained will be discussed. Comment will be made on films available for this purpose, the effects of different light placement, and the darkroom techniques employed. In addition, an interesting procedure of photo-copying maps on a light table will be demonstrated.

Film—"CAVES OF WAR"
Introduction by John Davidson
1966, 16mm, sound, color, 11.5 min
Producer & Director: John Davidson

This film deals with the saltpeter caves of West Virginia. Comments will be made on its script and production.

PHOTOGRAPHING CAVE LIFE

Charles E. Mohr

The techniques of macro-photography will be discussed in reference to capturing cave organisms ¼ in or less in actual size. Methods for photographing cave invertebrates above and below water and for recording the life-history sequences of salamanders and pack rats will also be presented. The benefits of photo-collecting as opposed to physical-collecting of cave life will be stressed.

THREE PIONEERS OF FRENCH CAVING DOCUMENTARY

David N. Brison

Background information will be supplied on each cinematographer and on the famous explorations that their films document. A short analysis will be given on specific aspects (i. e., lighting, editing, etc.) of their film technique.

Marcel Ichac
Film—"PADIRAC—THE BLACK RIVER"
1949, 16mm, sound (English & French), b&w, 17 min
Releaser: A. F. Films

Jacques Ertaud
Film—"PIERRE SAINT-MARTIN EXPEDITION"
1954, 16mm, sound (French), b&w, 23.5 min
Producer: Les Actualities Francaises

Georges Marry
Film—"SIPHON —1122 m"
1957(?), 16mm, sound (music only),b&w, 17 min
Producer: Cinepress

GEOGRAPHY/EXPLORATION SESSION

THE SIERRA DE EL ABRA: MEXICO'S MOST INTERESTING KARST REGION

William H. Russell
University of Texas
Austin, Texas
and
R. S. Harmon
Manned Spacecraft Center
Houston, Texas

Forming the easternmost range of the Sierre Madre Oriental, the Sierra de El Abra is one of the most interesting and complex karst regions of Mexico. Geologically, the Sierra de El Abra region is a paleo-reef, lagoonal trend, folded and warped during the Laramide Orogeny. Subsequent erosion exhumed the shallowly buried reef and left it open for groundwater invasion which resulted in the intense karstification present today.

The major development of caverns in the region has occurred by deep phreatic solution, producing large chambers and deep vertical conduits. At first localized in extent, subsequent erosion and, to a slight amount, the surface streams have resulted in a few well-integrated, hydrologic drainage networks.

The Sierra de El Abra region is potentially the most valuable karst region of Mexico, and as such the region has been the focal point for Mexican speleological research. Biological and geological researchers of the Association for Mexican Cave Studies (AMCS) have begun to understand the ecology and speleogenesis of the region, and practical applications of their research to benefit the region can now be considered a realistic future goal.

WHAT OUGHT A CAVE MAP TO SHOW?

James Hedges
U. S. Marine Band
Washington, D. C.

Published cave maps often contain so little detail that they are of slight use to persons not famiilar with the caves shown. Only a little more effort would be required to clothe passage outlines with geographic, geologic, biologic, and meteorologic data basic to the work of many specialists. Draughtsmen (and map users) often are hampered by the lack of enough commonly accepted symbols which adequately portray the significant features of caves. A revised, expanded list of cave map symbols is offered to supplant the NSS Standard Map Symbols of 1961. Even the most detailed cave map will not be an effective vehicle of communication if it is cluttered, cramped, or lettered poorly or is in other ways offensive to the eye. Cave cartographers should strive to produce maps which convey information in a graceful manner.

RECENT DISCOVERIES IN THE BURNSVILLE COVE AREA OF WEST-CENTRAL VIRGINIA

Nevin Davis Fred Wefer Jack Hess
State College, Pa.

Burnsville Cove has been studied in the past and a comprehensive masters thesis was completed by George Deike in 1960. His studies centered around Beathing Cave. More recently spelunkers have pushed Better Forgotten Cave to a depth of 420 ft and a length of 4100 ft. Butler Cave has had an extension of over ½ mile, and a third siphon has been discovered in Breathing Cave, adding 1000 ft to the cave's length. Over 20 miles of known cave passages lies beneath the Cove.

Stream tracing has proven the connection between all major streams in Butler and Breathing Caves with Aqua Spring and Cave. Other tracings have shown sources for the water in Cathedral and Emory Springs.

SINKS OF THE RUN CAVE

William K. Jones
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A small stream starts near the southern tip of Muddy Creek Mountain, Greenbrier County, West Virginia. The stream trends SSW down Davis Hollow for about 1 mile to the contact of the Greenbrier Limestone (Alderson member) and the Mauch Chunk Sandstone. Two hundred feet beyond this contact, the stream enters a cave opening, reverses its direction of flow to cross back under its surface course, and continues into the mountain for a surveyed distance of 2005 ft in a NE direction. The passage has three vertical drops which require rigging and terminates in a siphon 250 ft below entrance level.

THE WHITE RIVER PLATEAU (COLORADO) PROJECT—1969 AND 1970

Jens Munthe, Jr.
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Boulder, Colorado

Although long known to possess caves, the White River Plateau of western Colorado did not receive any concentration of attention from Colorado cavers until the 1969 caving season, which extends only from late May through early October due to the 10,000-ft altitude and lack of maintained roads. With the organization of the Plateau Project and much work by the Colorado and Colorado School of Mines Grottos during 1969, the number of known Plateau caves reached 24 by the end of that year, including three with surveyed passage over 1 mile. The Project's organization and procedures are described. An attempt is made to analyze the geological conditions favoring cave formation in the area. Emphasis is placed on the most recent (summer 1970) accomplishments of the Project.

A RELICT CAVE SYSTEM IN THE BAMBUI LIMESTONE, RIO JACARE VALLEY, BAHIA, BRAZIL

William C. Sinclair
U. S. Geological Survey

The Brejoes Cave appears to be a remnant of a cavern system that formerly was more extensive. The middle reach of the Rio Jacare is deeply incised in the gently-dipping, thin-bedded Bambui Limestone. The narrow, steep-walled canyon, which is more than 350 ft deep in places, is interrupted abruptly, near the village of Brejoes, then continues from about 1.5 miles downstream. This interval is underlain by about 3 miles of cave passages at several levels.

The principal cave passages have developed along the major regional joint patters. Blocks and slabs of limestone, spalled from the ceiling and walls, litter the floor throughout most of the cave passages indicating that collapse is the dominant process under the present semi-arid climate. Speleothems are present in favored places but are not common.

The Rio Jacare sinks into the talus of the canyon floor near the cave entrance, reappears at several places within the cave, and flows out the downstream entrance. To enter the cave as surface flow, the river would need to rise 70 ft and spill over the talus at the entrance. This has apparently not happened recently, but evidence of higher river levels in the geologic past are abundant.

FACTORS AFFECTING EXPLORATION IN THE MYSTERY AND RIMSTONE CAVE SYSTEMS, MISSOURI

Terry L. Pitchford
Jennings, Mo.
Joseph Walsh
Jerseyville, Ill.
Gary R. Schaecher
Carbondale, Ill.

In 1966, Little Eygpt Grotto started exploration and survey work in Mystery Cave of Perry County, Missouri. During the next two years mapping of most of the readily accessible parts of the cave was completed, with over 11 miles of passage discovered. It became apparent from geographic considerations of the large sinkhole plain under part of which Mystery lay that only a part of the subsurface drainage was accounted for by the Mystery System. This, and the fact that many Mystery passages were obviously only segments of truncated larger passages that must exist adjacent to the known cave, led to surface search for other cave systems. In 1968, Rimstone River Cave, a cave system of at least the magnitude of Mystery, was discovered. A year of active exploration and mapping followed, with subsurface wind and water drainage analysis being a directing factor. The possibility of a connecting passage between Rimstone and Mystery in the future exists. Recently, in March 1970, what may be the entrance to another large cave system adjacent to Mystery and Rimstone, the Thunder Hole Cave, was discovered during the investigation of the spring resurgences that drain the sinkhole plain and discharge the waters of Rimstone and Mystery. Other exploration, mapping, and surface study is actively going on at present, with most of the cave work being done in Rimstone. Publishing of a section map with karst features and all known caves and cave passages of the entire sinkhole plain is planned for the future.

GENERAL/TECHNICAL SESSION

THE LASER AS A CAVE-SURVEYING INSTRUMENT

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Indiana University
Bloomington, Ind.
Richard J. Blenz
Physics Dept.
Indiana University
Bloomington, Ind.

Preliminary tests having indicated the usefulness of a small helium-neon laser in several cave surveying applications, a cave-portable system has been designed. The laser adapts readily to leveling and plane table operations, solving problems encountered when look-through optical instruments are used in a dark environment. The laser beam's brilliance and non-divergence make it extremely useful in making sightings at very long range. With the addition of mirrors and other simple parts, angle-measuring devices and a parallax-type range finder can be built. The problems of cost, bulk, and power supply are expected to diminish with the advancement of laser technology.

A RESISTIVITY METHOD FOR CAVE DETECTION

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University of Kentucky
Lexington, Kentucky

An inexpensive and effective method has been developed for location of caves from the surface without the necessity of an underground transmitter. Present depth capacity is 60 ft. Passages 10 ft in diameter are easily detected.

A linear array of 20 brazing rods is placed in the ground 5 ft apart with an additional electrode placed about 110 ft from one end. A 90-V battery is placed across the extreme electrodes. Voltages are read across all pairs of inner electrodes 20 ft apart using a meter capable of 0.25-V full scale. The lone battery electrode is then moved to the other end of the array and voltage again read. Self-potential corrections are necessary and may be made either by reading voltages before applying the battery or by reversing battery polarity and averaging the readings.

The area observed approximates an inverted triangle in section with its base lying along the axis of the electrode array and its depth 0.6 times the base. Thickness is about 20 ft. Simple mathematical and graphical treatment of the data yields the location and size of air-filled cavities. Poor resolution makes separation of adjacent passages difficult. Metal fences with metal stakes, buried pipes, hard dry ground, and perhaps stray house currents interfere. Total cost of needed equipment is less than $50, and most is useful for other purposes. Batteries are good for several runs. Total time for one run using two men is one hour.

CAVE DIVING: ITS ENJOYMENT, NECESSITY, AND ACCIDENTS

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This paper is an illustrated slide show depicting five years of research on the aspects of diving in dry cave sumps, sinks, and springs. The topics covered include: why dive caves, dangers, suggested minimum training, specialized equipment, and techniques employed. A report of recent disasters and some observations is also included. The slide presentation is supplemented with a display of selected special equipment and a printed brochure.

It is hoped that this presentation will create a desire to form an NSS Committee on Cave Diving in order to properly analyze and distribute information concerning locations, techniques, and accidents in the USA.

DETERMINING LONGITUDE AND LATITUDE OF CAVE LOCATIONS BY COMPUTER METHODS

Ernst H. Kastning

Often the longitude and latitude of cave entrances are tabulated as part of a regional survey of caves. These coordinates are usually determined by reading them on a USGS topographic survey map upon which the cave location has been marked. Since the topo sheets are not graduated in seconds of arc, each location must be determined with either a specially scaled ruler or by mathematical computation.

A method which eliminates the tedium of hand calculation is presented here and is easily applicable to computer data processing. Human errors are thereby minimized. Inputs to the program are the topo sheet series (7.5-, 15-, 30-minute, etc.), the coordinates in degrees, minutes and seconds for the lower left corner of the sheet, and the physical dimensions of the topographic map (i.e., the width at the top and bottom of the map and its height). For each cave an identification number, distances of the cave location from the left and bottom margins of the map and an estimate of an accuracy tolerance are fed into the program as input data.

Each topographic map is treated as a trapezoid and coordinates in degrees, minutes, and seconds are calculated based on this geometry. Batch processing will print out a list of the caves and their coordinates for each topographic sheet requested.

SPELEAN HISTORY SESSION

"THE SUCKER'S VISIT TO THE MAMMOTH CAVE" by Ralph Seymour Thompson: A Background Study

John F. Bridge

During the period of reconstruction following the Civil War, the lower Green River country in Kentucky was a backwater about which little has been written. This book contains a unique account of a trip through this region in 1870 by a small group of "Suckers" from Illinois. The descriptive narrative provides valuable information about the sociology of the people that inhabited the region and a fine description of the physical environment. Thompson's sarcastic style is typical of midwestern provincialism, but his love for nature and appreciation of natural wonders of his homeland place him among the few 19th-century American conservationists who understood man's destructive influence on his environment.

The trip to Mammoth Cave began in Albion, Illinois. The 208 miles took 10 days in a horse-drawn wagon. The party had intentionally carried a minimum of food and supplies, planning on hunting and local acquisitions to provide the remainder of the necessary food. Their curiosity about the land and its inhabitants was amply fulfilled as they learned by first hand experience how scarce food was and how desperate living conditions were in Green River country. The second section of the book describes the trip through the cave and incidents in and around the cave, Bowling Green, and the traumatic riverboat return trip to Albion.

Ralpha Seymour Thompson was born near Albion, Illinois, in 1847. His father was an English immigrant with slightly eccentric ideas. As Ralph's mother died while he was very young, his father raised and educated him at home, never trusting the schools for Ralph's education. The measure of the elder Thompson's success as an educator is the accomplishments of his son who became a successful druggist and newspaper editor and publisher and who in later years organized a successful manufacturing firm in Springfield, Ohio. Thompson wrote two other books. One book was a handbook for farm housewives, and the other a textbook on agricultural chemistry. Unfortunately he never again wrote about the vanishing frontier wilderness which he loved.

NOTES ON THE EARLY USE OF THE NAME "MAMMOTH CAVE"

Ernst H. Kastning

Recently an antique map of Mammoth Cave in Kentucky was located by a Miss Joan Titley while doing research on the Revolutionary War letters of Dr. Frederick Ridgley, brother-in-law of Charles Wilkins. A letter written by him on March 15, 1811, to a Dr. Benjamin Rush in Philadelphia included a copy of the Eye Draught Map of Mammoth Cave, one of three known versions.

This was the earliest known use of the name "Mammoth Cave" until recently when an old newspaper article reprinting a letter dealing with the cave came to light. It appeared in the April 20, 1810 edition of *The Enquirer* of Richmond, Virginia, vol. 6, no. 109, page 4, and was entitled:

The Subterranean Voyage
or
THE MAMMOTH CAVE
Partially Explored.

(From a gentleman in Bowling Green, Kentucky, to his friend in Russelville)

Bowling Green, January 21st, 1810

THE REDISCOVERY OF NICHOLSON'S LOST PIT

William R. Halliday

Various authoritative sources have listed the depth of Carlsbad Caverns as 1350 ft. This arose from a claim by the controversial spelunker Frank Nicholson who in 1930 led an expedition to Carlsbad Caverns under the sponsorship of the New York *Times*. In the intervening years the pit where Nicholson claimed to have penetrated deeper than the Lake of the Clouds was "lost". By the use of the crude sketch map in Nicholson's paperbound booklet on his expedition, however, it was possible to rediscover and descend the pit—and it's quite a pit! Details will be provided.

RIDDLES OF MAMMOTH CAVE

Harold Meloy

A summary of Mammoth Cave historical research work during the past several years and mention of unresolved matters currently under investigation.

FIRST IN AMERICAN CAVES: THE LIFE AND SPELUNKING OF THE REVEREND HORACE C. HOVEY

William R. Halliday

Horace C. Hovey was born in an Indiana log cabin in 1833. As a boy, he explored many caves in Indiana, including Wyandotte Cave; his articles thereon were published by the *Indianapolis Journal* and *New York Tribune;* they were later plagiarized in Stelle's book on that cave. After a long gap because of family matters, Hovey suddenly was acclaimed America's leading speleologist. His influence extended so far past his 1914 death that in 1930 William M. Davis referred to Hovey material in his classic deductive study of caves.

DELTIOLOGY AND SPELEAN HISTORY

Peter M. Hauer

Deltiology, the pursuit of picture post card collecting, is of interest to the cave historian. Issued by the hundreds since 1898, cave post cards can provide information for the history of specific caves, for state or regional cave surveys, or for knowledge of early cave photographers. An actual viewing of a sampling of cards on caves is an invaluable tool in the appreciation of this informative medium.

Information for Contributors To The Bulletin

Papers in any discipline of speleology or any cave-related topic are considered for publication in the BULLETIN. Papers may be a technical article on some cave-oriented geological or biological research, a review paper on a speleological topic, or a speculative discussion of theory. We particularly welcome descriptive or geographical articles about significant caves or cave areas, especially if comments on speleogenesis, biological surveys, historical significance, etc. are included. Articles on other topics such as cave conservation, history, etc. are also invited.

Articles in the biological sciences should be sent to the Biology Editor, David C. Culver, Dept. of Biological Sciences, Northwestern University, Evanston, Illinois 60201. Articles in the line of geology or geography should be sent to the Earth Sciences Editor, William B. White, Materials Research Laboratory, the Pennsylvania State Univ., University Park, Pa. 16802. Articles not falling in either of these categories may be sent to the Managing Editor, David Irving, Science Applications, Inc., P. O. Box 2351, La Jolla, California 92037.

At least one copy of the manuscript, typed and doublespaced, should be submitted to the appropriate Editor. The upper limit for length is about 10,000 words or approximately 40 pages of manuscript. This limit may be waived where a paper has unusual merit. Photographs and line drawings should be submitted with the manuscript. Because of cost, only illustrations essential to the presentation should be included. Photographs must be sharp, with high contrast. All line drawings should be done with lettering instruments or other satisfactory means. Typed lettering is not ordinarily satisfactory. Captions will be set in type and added. All drawings must be inked, with India Ink or a satisfactory substitute. In case of doubt regarding length or illustrations, consult the Editor.

For general style, see papers in this BULLETIN. Abstracts, which should be brief and informative, are required for all papers. Captions are required for all illustrations, and all unusual symbols used should be explained. References to the literature should be by author and date, with specific pages where desirable. Literature cited should be listed in an end bibliography with entries arranged alphabetically by author's last name. Consult bibiliographies in this BULLETIN for general format.

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